APPENDIX C
Natural Hazard Risk Assessment

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Why Are We Concerned with Exposure and Probability, Not Just Hazards?

If a river overflows its bank in an uninhabited area with no roads and no buildings, it is a flood, but not a flood disaster. If a major earthquake occurs in the desert of southeastern California where no one lives, it is still an earthquake, but not an earthquake disaster. This hazard mitigation plan is concerned about the location of people, buildings, and infrastructure relative to the hazards of floods, earthquakes, wildfires, and landslides – our hazard exposure.

Hazards also need to be expressed with some sort of probability. Typically, hazards that cause disasters are not common, or these disasters would have long ago triggered an increase in response capability and hazard mitigation. For example, Bay Area cities and counties have adopted mitigation strategies and building codes that allow moderate earthquakes to occur with minimal damage. Because disasters are rare, the probability information on their future occurrence is incomplete or subject to large errors. The probability that a hazard will result in a disaster is our risk.

A complete risk assessment should identify:

- the existing land uses, buildings, infrastructure, and critical facilities located in each of these hazard areas (exposure);
- a general description of land use and development trends along with associated anticipated changes in exposure;
- an estimate of the potential deaths and injuries, property damages (dollar losses), and functional losses (disruption) based on exposure and vulnerability of various types of structures; and
- estimates of the probabilities of these losses over time.

The risk assessment ABAG has created for the Bay Area is incomplete. However, ABAG and the local governments that have created this plan are committed to improving the risk assessment over time. The risk assessment in this 2009-2010 MJ-LHMP is much more complete and comprehensive than that included in the 2004-2005 MJ-LHMP. For example, better information is included on the vulnerability of local governments' own facilities, as well as the region's housing stock and commercial/industrial buildings. But the structural vulnerability information is incomplete; thus, information on improving that information is including in several in the mitigation strategies including, for example, infrastructure systems (INFR a-1), soft-story housing (HSNG c-4), and government facilities (GOVT a-1). The structural vulnerability information also changes over time; for example, the MetroCenter headquarters facility of MTC and ABAG was designed to meet current codes in 1983, but improvements to those codes and structural assessment techniques showed the facility to be a "partial collapse hazard." Retrofit completed in 2007 has strengthened the facility. The hazard maps change over time; for example, FEMA has been upgraded the older Flood Insurance Rate Maps (Q3 FIRMs) to create more modern D-FIRMs (digital FIRMs).

The following sections focus on describing the most significant natural hazards affecting the San Francisco Bay Area related to earthquakes and weather (fire, flooding, landslides, drought, and climate change), as well as tsunamis, dam failure, and levee failure.

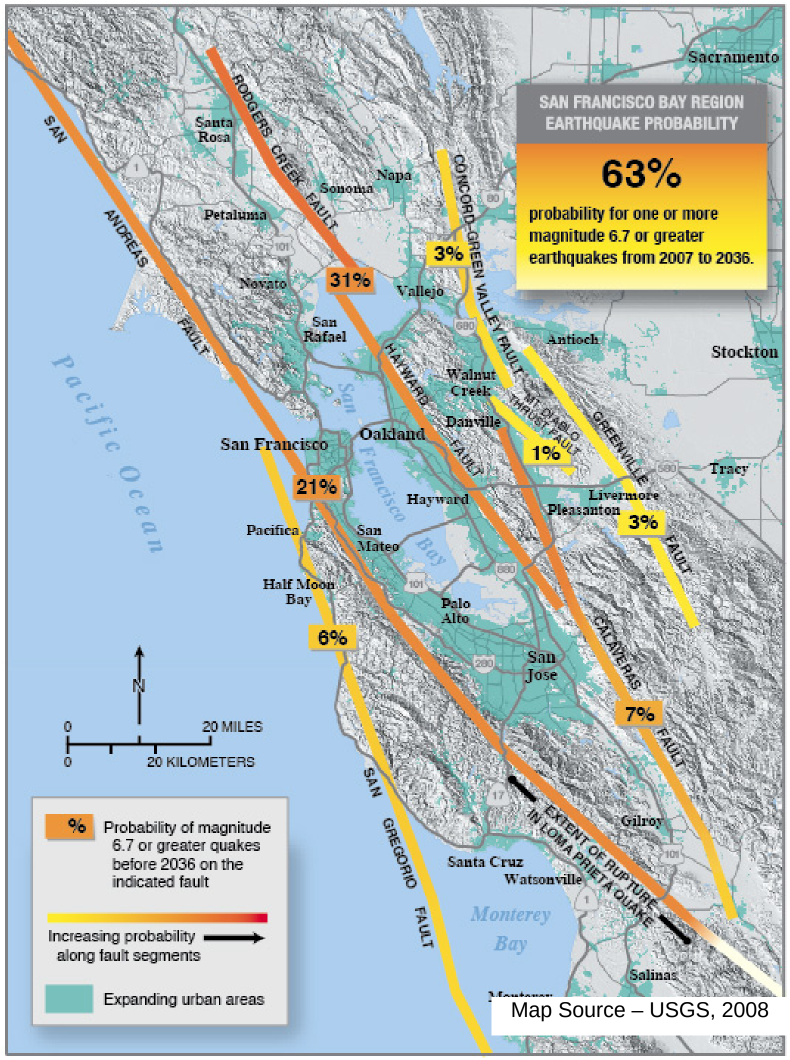
Earthquakes

Probability of earthquake-related hazards

The Bay Area is in the heart of Earthquake Country. The Bay Area is crossed by many active faults. This map figure shows that major active faults run through or adjacent to all nine Bay Area counties.

While research by the U.S. Geological Survey (USGS) has provided more reliable probability information for future Bay Area earthquakes than for any other area of the country (63% probability of a magnitude 6.7 or larger earthquake), it has a wide error range – plus or minus 22%[1]! Smaller earthquakes are more likely to occur and can still produce significant damage over localized areas.

Probability of the rupture of individual faults has also been prepared by USGS, as shown in ***Table 1***.[2]



Map Source – USGS, 2008

Probability information for the West Napa, Monte Vista and Maacama faults unavailable in the 2005 MJ-LHMP plan has been included in this MJ-LHMP update. Probability estimates for these faults was developed by the 2008 USGS Working Group on Earthquake Probability.

Location and extent of earthquake-related hazards

Earthquakes result in five different hazards that have been mapped in the Bay Area. The following sections describe those hazards, as well as reference the map plates showing the location and extent of the hazard in the Bay Area.

[1] Source – 2008. USGS Working Group on Earthquake Probabilities. ***Forecasting California's Earthquake- What Can We Expect in the Next 30 Years?–*** USGS Fact Sheet 2008-3027 at http://pubs.usgs.gov/fs/2008/3027/ and *The Uniform California Earthquake Rupture Forecast, Version 2* - USGS Open-File Report 2007-1437 at http://pubs.usgs.gov/of/2007/1437/.

[2] The probability information provided by the USGS for earthquakes on each fault also applies to the associated earthquake-related hazards (ground shaking, liquefaction, landslides, and, except for faults that do not extend to the surface, fault surface rupture). Tsunamis probabilities are more complicated, however, as noted on page C-24.

TABLE 1 – Probabilities of Selected Earthquake Scenarios Occurring in the Next 30 Years and Slip Rates on Associated Fault Segments [*based on USGS Working Group on Earthquake Probabilities, 2003 and 2008**], [*Scenario maps on ABAG web site are shaded.*]

Fault	Segment (s)	Average Long-Term Slip Rate (mm / year)	% Probability of Characteristic Quake 2002-2031	% Probability of Quake ≥ 6.7 2007-2036
N. San Andreas	Santa Cruz Mountains (SAS)	17	2.6	4.0*
	Peninsula (SAP)	17	4.4	0.6*
	North Bay (SAN)	24	0.9	0.04*
	Ocean (north of Bay Area – SAO)	24	0.9	1.9*
	South Bay Segments (SAS + SAP)	17	3.5	4.4*
	Central Bay Segments (SAP + SAN)	17 – 24	0.0	0.0*
	Northern Segments (SAN + SAO)	24	3.4	4.1*
	Bay Area Segments (SAS+SAP+SAN)	17 – 24	0.1	0.05*
	Central + North (SAP + SAN + SAO)	17 – 24	0.2	0.2*
	Entire – Repeat of 1906 (SAS + SAP + SAN + SAO)	17 – 24	4.7	3.8*
	Floating M6.9	17 – 24	7.1	6.8
Hayward/Rogers Creek	Southern (HS)	9	11.3	4.8*
	Northern (HN)	9	12.3	1.2*
	Entire (HS + HN)	9	8.5	8.8*
	Rogers Creek (RC)	9	15.2	16.3*
	HN + RC	9	1.8	2.1*
	HS + HN + RC	9	1.0	1.2*
	Floating M6.9	9	0.7	0.7
Calaveras	Southern (Outside Bay Area - CS)	15	21.3	0.0*
	Central (CC)	15	13.8	0.0*
	CS + CC	15	5.0	0.1*
	Northern (CN)	6	12.4	2.4*
	CC + CN	6 – 15	0.3	0.3*
	CS + CC + CN	6 – 15	2.0	3.6*
	Floating M6.2	6 – 15	7.4	0.0
	Floating M6.2 on CS + CC	15	7.4	0.0
Concord/Green Valley	Concord (CON)	4	5.0	0.1
	Southern Green Valley (GVS)	5	2.3	0.0
	CON + GVS	4 – 5	1.6	0.3
	Northern Green Valley (GVN)	5	6.1	0.0
	Entire Green Valley (GVS + GVN)	5	3.2	0.4
	Entire (CON + GVS + GVN)	4 – 5	6.0	2.7
	Floating M6.2	4 – 5	6.2	0.0
San Gregorio	Southern (Outside Bay Area - SGS)	3	2.3	2.1
	Northern (SGN)	7	3.9	3.9
	SGS + SGN	3 – 7	2.6	2.6
	Floating M6.9	3 – 7	2.1	2.0
Greenville	Southern (GS)	2	3.1	0.7
	Northern (GN)	2	2.9	1.0
	Entire (GS + GN)	2	1.5	1.4
	Floating M6.2	2	0.4	0.0
Mt. Diablo Thrust	Mt. Diablo Thrust (MTD)	2	7.5	0.7*
Maacama - Garberville	Southern (only part in Bay Area)	9*	*Not available*	*12.6**
Monte Vista - Shannon	Monte Vista Segment	0.4*	*Not available*	*0.02**
West Napa	Entire Segment	1*	*Not available*	*0.3**

Location and Extent of Surface Rupture

Earthquakes occur in the Bay Area when forces underground cause the faults beneath us to rupture and suddenly slip. If the rupture extends to the surface, we see movement on a fault (*surface rupture*). Because faults are weaknesses in the rock, earthquakes tend to occur over and over on these same faults.

The California Geological Survey (CGS) publishes maps of the active faults in the Bay Area that reach the surface as part of its work to implement the requirements of the Alquist-Priolo Earthquake Fault Zone Act. These maps show not only the most comprehensive depiction of fault traces that can rupture the surface, but also the zones in which cities and counties must require special geologic studies to prevent the building of structures intended for human occupancy from being built *and* in which the surface rupture hazard must be disclosed in real estate transactions. The regional depiction of the location of this hazard is on ***Plate 1*** *– Fault Surface Rupture Hazard*.

In some respects, fault rupture is a relatively minor problem in earthquakes. For example, strong earthquakes can occur when the fault rupture does not extend to the surface, and fault-related damage is rare when compared to shaking-related damage. Neither the Loma Prieta nor the Northridge earthquakes resulted in surface rupture. In addition, the major thrust faults listed in ***Table 1*** have not experienced surface rupture. While the faults shown on ***Plate 1*** only include those faults that have experienced surface rupture, only structures that are *directly astride* the rupturing fault trace will be damaged in a future earthquake, not all of the structures in the study zones.

On the other hand, while houses and other buildings can avoid building astride a fault, roads and pipelines for gas, water, and wastewater, as well as electrical and telecommunications utilities that serve those buildings, cannot avoid crossing faults. Some pipeline rupture can be mitigated through engineering design if some parameters are known about the fault.

Many of the faults in the Bay Area are well studied, but there is still much that is unknown about them, including how much they will slip in the location of a pipeline crossing during a future earthquake or the exact location of a fault trace. Furthermore while the slip zone in rock is very localized, in thick soils the zone can be quite wide when the surrounding soil is dragged along with the fault, called warping. Much study continues to be done in this area, including the development of a fault displacement hazard assessment, an effort being led by the California Geological Survey.

The amount of ground displacement can be quite large, particularly when a major strike-slip fault is involved. For example, in a study conducted by ABAG examining the potential impact of this hazard on road closures[3], the amount of horizontal displacement on the large strike-slip faults was estimated as 2 – 4 meters, and the amount of vertical displacement was estimated as 0 – 0.4 meters, with actual values sometimes reaching double these values.

Maps of fault rupture hazard for individual local governments are on line at http://quake.abag.ca.gov/faults.

[3] Source – 1997. Perkins, J., and others. ***Riding Out Future Quakes*** – ABAG, 198 pp. See fault rupture discussion on pages 15-19.

Location and Extent of Ground Shaking

The fault rupture of the ground generates vibrations or waves in the rock that we feel as *ground shaking*. Larger magnitude earthquakes generally cause a larger area of ground to shake hard, and to shake longer. As a result, one principal factor in determining shaking hazard is the magnitude of expected earthquakes. However, an earthquake shakes harder in one area versus another based not only on the magnitude, but also on other factors, including the distance of the area to the fault source of the earthquake and the type of geologic materials underlying the site, with stronger shaking occurring on softer soils. Earthquake intensity measures the strength of ground shaking in an individual earthquake at a particular location. ABAG and the U.S. Geological Survey (USGS) have developed several maps to aid in depicting shaking intensity, and thus ground shaking hazard.

- ABAG, in conjunction with scientists at USGS, has developed shaking intensity maps for 18 likely future earthquakes, as shown on ***Plates 2 – 19*** – *ABAG Earthquake Shaking Scenarios*. These maps are appropriate for use in disaster exercises and in earthquake disaster planning.
- USGS has also developed several earthquake shaking intensity maps for anticipated future earthquakes. These maps are based on the ground motion models that are used to generate ShakeMaps for large and moderate earthquakes immediately after these earthquakes occur. A comparison of the USGS ShakeMap versus ABAG Earthquake Shaking Scenario map for the North and South Hayward fault scenario has been included as ***Plate 20*** for information. As can be seen from this comparison, the ABAG Earthquake Shaking Scenario maps show higher shaking near the fault than the ShakeMaps for the large strike-slip faults that are common in the Bay Area. Estimating ground motions near rupturing faults is an active area of earthquake research. Records of strong ground motions with peak velocities consistent with the ABAG model were obtained from near-fault stations for the recent 2002 Denali and 1999 Chi-Chi earthquakes. Because of our desire to be conservative, ABAG is using the ABAG Earthquake Shaking Scenario maps for this disaster planning effort.

As is obvious when examining the explanation on these maps, higher modified Mercalli intensities translate into higher shaking. The impact of this increased shaking varies. For example, higher shaking can translate into higher numbers of landslides, greater areas of liquefaction, and more damaged buildings. More information on this subject is available at http://www.abag.ca.gov/bayarea/eqmaps/doc/mmi.html for the modified Mercalli intensity (MMI) scale itself, and at http://www.abag.ca.gov/bayarea/eqmaps/doc/1998gs.html for what higher ground shaking means in a way that is more quantified than the MMI scale itself. This information was developed by ABAG for the U.S. Geological Survey in 1998[4].

Finally, it is often useful to have a single hazard map containing the shaking hazard information for the Bay Area for long-term risk analysis because an earthquake can happen on any fault at any given time, and a composite maps shows the greatest potential for shaking at any location from all faults. USGS cooperated with CGS, the California Seismic Safety Commission (CSSC),

[4] Source – 1998. Perkins, J. ***The San Francisco Bay Area – On Shaky Ground - Supplement*** – ABAG, 28 pp. See discussion on meaning of MMI on pages 2-11. Note – this information is also on the web at http://www.abag.ca.gov/bayarea/eqmaps/doc/1998gs.html.

TABLE 2 – SUPPLEMENTARY INFORMATION FOR PLATES 2-20: Modified Mercalli Intensity Scale Summary Descriptions and "Official" Full Description

MMI Value	Description of Shaking Severity Used on Current Maps	Summary Damage Description Used on 1995 Maps	"Official" Full Description (from Richter, C.F., 1958. Elementary Seismology. W.H. Freeman and Company, San Francisco, pp. 135-149; 650-653.)
I.			Not felt. Marginal and long period effects of large earthquakes.
II.			Felt by persons at rest, on upper floors, or favorably placed.
III.			Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV.			Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.
V.	Light	Pictures Move	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI.	Moderate	Objects Fall	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle).
VII.	Strong	Nonstructural Damage	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII.	Very Strong	Moderate Damage	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX.	Violent	Heavy Damage	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas sand and mud ejected, earthquake fountains, sand craters.
X.	Very Violent	Extreme Damage	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI.			Rails bent greatly. Underground pipelines completely out of service.
XII.			Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

and State OES to develop such a "composite" scenario map. There are two principal caveats to use of this probabilistic seismic hazard map.

(1) It incorporates probability information that has a wide margin of error. As stated earlier, while recent research by USGS has provided more reliable probability information for future Bay Area earthquakes than for any other area of the country (63% of a magnitude 6.7 or larger earthquake), it has a wide error range (from a low of 41% to a high of 84%, or plus or minus 22%[5])! In addition, the December 2003 San Simeon earthquake occurred in an area shown on this map as having less potential for strong shaking than many other areas of coastal California.

(2) The shaking intensity levels are based on the ShakeMap models, and may underestimate the hazard near the Bay Area's large strike-slip faults, as noted above.

See ***Plate 21*** – *Earthquake Shaking Potential* for a regional depiction of this hazard map. The map used in this updated plan remains the 2003 version of this map. A newer map based on the 2008 probabilities is undergoing development, but the newer map (1) is not available, as of October 2009, in digital form, and (2) does not incorporate local ground conditions, making it less suitable for local city and county uses than the 2003 map.

We anticipate that improved versions of the Earthquake Shaking Potential map will become available for future updates of this plan. In addition, shaking hazard maps associated with individual faults are being improved over time.

See http://quake.abag.ca.gov/mapsba.html for more information and local government-specific depictions of the 20 earthquake shaking hazard maps for individual earthquake scenarios, as well as the Earthquake Shaking Potential map.

Location and Extent of Liquefaction

Ground shaking can lead to *liquefaction.* When the ground liquefies in an earthquake, sandy or silty materials saturated with water behave like a liquid, causing pipes to leak, roads and airport runways to buckle, and building foundations to be damaged. As with ground shaking, several types of maps aid in depicting this hazard.

- Liquefaction susceptibility maps show areas with water-saturated sandy and silty materials that have the potential to liquefy if shaken hard enough. ***Plate 22*** shows a map of liquefaction susceptibility for the Bay Area published by USGS showing various levels of liquefaction susceptibility (as updated in 2006). ***Plate 23*** shows the liquefaction susceptible areas as depicted by CGS as part of its mapping program mandated by the Seismic Hazards Mapping Act. Unlike ***Plate 22***, the CGS map groups most of the moderate to very high susceptible areas shown on the USGS map into official seismic hazard map zones where real estate disclosure and hazard analysis are required. Note, however, that this type of map is only available for a portion of the Bay Area.
- Liquefaction hazard maps for specific earthquake scenarios show areas where the ground is both susceptible to liquefaction and that are likely to be shaken hard enough in a particular earthquake to trigger liquefaction. These maps are depicted in ***Plates 24 – 41***

[5] Source – 2003. USGS Working Group on Earthquake Probabilities. ***Is a Powerful Earthquake Likely to Strike in the Next 30 Years?*** – USGS Fact Sheet 039-03 at http://geopubs.wr.usgs.gov/fact-sheet/fs039-03/fs039-03.pdf.

and are a combination of the liquefaction susceptibility mapping and the ground shaking exposure mapping.

TABLE 3 –
SUPPLEMENTARY INFORMATION FOR PLATE 22: Liquefaction Susceptibility Map

MMI Value	**Full Description** (from Knudsen and others, 2000.(Knudsen, K.L., Sowers, J.M., Witter, R.C., Wentworth, C.M., and Helley, E.J., 2000. ***Preliminary Maps of Quaternary Deposits and Liquefaction Susceptibility, Nine-County San Francisco Bay Region, California***: U. S. Geological Survey Open-File Report 00-444. Digital Database by Wentworth, C.M., Nicholson, R.S., Wright, H.M., and Brown, K.H. Online Version 1.0.) and Witter and others, 2006 (USGS Open-File Report 2006-1037. See http://pubs.usgs.gov/of/2006/1037/)
Very High	Very High
High	High
Moderate	Moderate
Low	Low
Very Low	Very Low

The following additional information on liquefaction affects is from Perkins, 2001.[6]

Liquefaction damage, Marina District, 1989 Loma Prieta, California, Earthquake
Source – M. Bennett, U.S. Geological Survey

When the ground **liquefies**, *sandy materials saturated with water can behave like a liquid, instead of like solid ground. The ground may sink or even pull apart. Sand boils, or sand "volcanoes," can appear.*

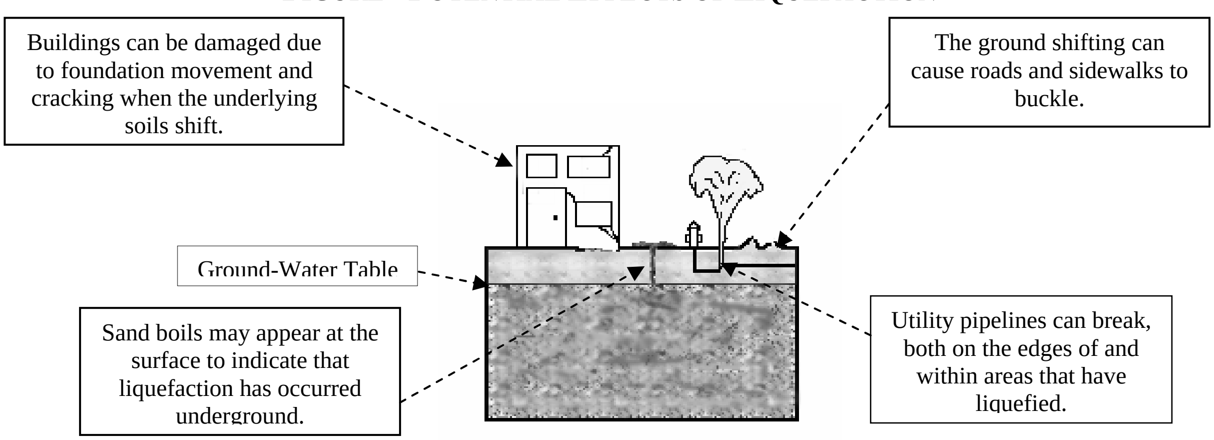
Liquefaction can cause ground displacement and ground failure such as lateral spreads (essentially landslides on nearly flat ground next to rivers, harbors, and drainage channels) and flows.

Our most vulnerable land falls into two general categories:

1. *areas covered by the huge amount of fill poured into San Francisco Bay since 1845 to transform 77 square miles (200 square km) of tidal and submerged areas into land; and*
2. *areas along existing and filled stream channels and flood plains, particularly those areas with deposits less than 10,000 years old.*

Overall, **shaking does more damage** *to buildings and highway structures than liquefaction.* **But liquefaction damage can be a significant threat for underground pipelines, airports (especially runways), harbor facilities, and road or highway surfaces.**

FIGURE - POTENTIAL EFFECTS OF LIQUEFACTION



[6] Perkins, J.P., 2001. ***The REAL Dirt on Liquefaction***. ABAG: Oakland, CA. 25 pp.

CGS is developing hazard maps for more areas as further research is completed. When these maps become available ABAG will incorporate them into its hazard analysis. The list of mitigation strategies includes several relating to ways in which local governments can increase the speed of completion of hazard maps, particularly GOVT-d-10 and LAND-a-7.

ABAG has conducted extensive studies looking at the ways that liquefaction could potentially impact the Bay Area summarized in an ABAG report.[7] In general, the potential impacts to infrastructure are more significant than to building structures.

See http://quake.abag.ca.gov/liquefac/liquefac.html for more information and local government-specific depictions of these two liquefaction susceptibility and 18 liquefaction hazard maps.

TABLE 4 – SUPPLEMENTARY INFORMATION FOR PLATES 24-41: Liquefaction Hazard Maps (for Earthquake Scenarios)

Liquefaction hazard maps were created using a combination of liquefaction susceptibility maps and ground shaking scenario maps depicting modified Mercalli intensity. The following table shows how the maps were generated.

MMI Value	Description of Shaking Severity	Summary Damage Description Used on Perkins and Boatwright, 1995 Shaking Maps	Liquefaction Susceptibility Category				
			Very Low	Low	Moderate	High	Very High
V	Light	Pictures Move					
VI	Moderate	Objects Fall					
VII	Strong	Nonstructural Damage			Moderately Low	Moderately Low	Moderate
VIII	Very Strong	Moderate Damage			Moderate	Moderate	Moderate
IX	Violent	Heavy Damage			High	High	High
X	Very Violent	Extreme Damage			High	High	High

TABLE 5 – SUPPLEMENTARY INFORMATION FOR PLATES 24-41: Pipeline Leaks per Kilometer of Pipeline Exposed to Various Combinations of Modified Mercalli Intensity and Liquefaction Susceptibility in the Loma Prieta Earthquake

Showing qualitative descriptions of high, moderate, and moderately low are based, in part, on pipeline leak information from the Loma Prieta and Northridge earthquakes

MMI Value	Description of Shaking Severity	Summary Damage Description Used on Perkins and Boatwright, 1995 Shaking Maps	Liquefaction Susceptibility Category				
			Very Low	Low	Moderate	High	Very High
V	Light	Pictures Move	0.001	0.002	0.002	0.000	0.004
VI	Moderate	Objects Fall	0.011	0.007	0.010	0.002	0.005
VII	Strong	Nonstructural Damage	0.032	0.011	0.036	0.008	0.086
VIII	Very Strong	Moderate Damage	0.028	0.063	0.182	0.019	0.278
IX	Violent	Heavy Damage	**No Data**	**No Data**	**No Data**	**No Data**	**No Data**
X	Very Violent	Extreme Damage	**No Data**	**No Data**	**No Data**	**No Data**	**No Data**

[7] Source – 2001. Perkins, J. ***The San Francisco Bay Area – The Real Dirt on Liquefaction*** – ABAG, 25 pp. See discussion on "What Happens to Our Built Environment" on pages 11-19. Note – this information is also on the web at http://quake.abag.ca.gov/liquefac/liquefac.html.

Location and Extent of Earthquake-Induced Landslides

Ground shaking can also lead to ground failure on slopes, or ***earthquake-induced landslides***. While USGS has created several demonstration maps for this type of hazard, the best depiction is shown in ***Plate 42***, the CGS seismic hazard map for earthquake-induced landslides. As with the CGS liquefaction susceptibility map, this map is only available for a portion of the Bay Area.

CGS is developing hazard maps for more areas as further research is completed. As these maps become available, ABAG is continuing to incorporate them into its hazard analysis. The list of mitigation strategies includes several relating to ways in which local governments can increase the speed of completion of hazard maps, particularly GOVT-d-10 and LAND-a-7.

More detailed maps for individual local governments and additional landslide hazard information are available on line at http://quake.abag.ca.gov/landslide.

Past occurrences of Bay Area earthquake-related disasters

The fact that a devastating earthquake occurred in 1906 – the San Francisco earthquake – is common knowledge. Larger earthquakes generally affect larger areas; the San Francisco earthquake caused extensive damage in Oakland, San Jose and Santa Rosa. More recently, the 1989 Loma Prieta earthquake caused extensive damage in the Santa Cruz Mountains, as well as in Oakland and San Francisco tens of miles away. But many moderate to great earthquakes (over magnitude 6.0) have affected the Bay Area; Twenty-two such events have occurred in the last 165 years – for an average of one every seven and a half years.

There have been only three earthquake-related natural disasters in the Bay Area since 1950 – the September 3, 2000 Napa earthquake (declared a disaster in only Napa County), the 1989 Loma Prieta earthquake (declared a disaster in Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara, and Solano counties), and the April 1984 Morgan Hill earthquake (declared a disaster in Santa Clara County). In addition, the April 1964 Good Friday Alaskan earthquake triggered mitigation conducted for the tsunami warning in Marin County. See Appendix D and http://quake.abag.ca.gov/mitigation/disaster-history.html.

Exposure of the Bay Area to earthquake hazards

ABAG has focused its assessment of Bay Area earthquake vulnerability assessment by conducting several major analyses – three exposure analyses as part of its development of this multi-jurisdictional Local Hazard Mitigation Plan (with plans to conduct additional ones when more complete mapping is available), and three as part of earlier efforts.

Fault surface rupture hazard and exposure of existing land use

The analysis of the types of land use and facilities focuses on the California Geological Survey's map of surface fault rupture hazard study zones (***Plate 1***) described earlier under the Alquist-Priolo Earthquake Fault Zoning Act. These zones are not fault zones, but zones in which studies are required to ensure that no structures intended for human occupancy are placed across active faults. Thus, only a small fraction of the land use areas and infrastructure miles in these zones are actually subject to fault rupture.

- Of the 4.39 million acres of land in the Bay Area, 1.8% is in areas designed as subject to the study requirement of the Alquist-Priolo Earthquake Fault Zoning Act.
- 2.3% of the urban land is in one of these areas, versus 1.7% of the non-urban land.
- Types of existing urban land uses with the highest percentages in these areas are urban open (3.3%) infrastructure (2.3%), and residential use (2.3%).
- The percentage of urban land located in these areas ranged from a high of 4.4% in both Alameda and San Mateo counties to a low of 0% in San Francisco.

These percentages are based on information in ***Table 6:*** *Surface Rupture Hazard and Existing Land Use*. See ***Plate 1*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Fault surface rupture hazard and exposure of existing infrastructure

Rather than discuss the percentages of road miles in these areas, it is useful to note the number of road closures in these areas in various earthquake scenarios. See http://www.abag.ca.gov/bayarea/eqmaps/eqtrans/result.html and select a specific scenario. For example, of the 1,734 road closures expected in a future North-South Hayward fault earthquake, 520 will be due to surface rupture. (These estimates are from the 2003 update of the *Riding Out Future Quakes* report discussed earlier.)

Pipelines have different issues, particularly the large water importation aqueducts of the East Bay Municipal Utility District (EBMUD), the Hetch-Hetchy system administered by the Public Utility Commission of the City and County of San Francisco (SF-PUC), and the Santa Clara Valley Water District (SCVWD). These local government agencies have unique issues with each major fault crossing. While the average movement of a fault in a particular earthquake can be estimated, the predicted slip in a particular location is not well understood. The exact location of a future surface rupture is also not precisely known. Both of these issues make design of these pipelines difficult. EBMUD and other agencies are continuing to work on their fault crossing issues, in spite of major construction projects that have already been completed. Additional information on these projects is contained in Chapter 1 – Infrastructure.

TABLE 6 – Surface Rupture Hazard and Existing (2005) Land Use

	Total Acres	In Alquist-Priolo Earthquake Fault Rupture Study Zones	% of Land in Study Zones
Total	4,387,602	80,598	1.8%
Urban	1,139,000	26,040	2.3%
Non-Urban	3,248,602	54,557	1.7%
URBAN ONLY:			
Residential	555,463	12,581	2.3%
Mixed R+C	1,775	30	1.7%
Commercial/ Services	110,502	2,145	1.9%
Mixed C+I	3,344	26	0.8%
Industrial	72,125	1,208	1.7%
Military	30,549	92	0.3%
Infrastructure	205,807	4,667	2.3%
Urban Open	159,435	5,291	3.3%
URBAN ONLY:			
Alameda	180,056	7,914	4.4%
Contra Costa	184,775	3,490	1.9%
Marin	54,146	753	1.4%
Napa	35,727	402	1.1%
San Francisco	29,273	0	0.0%
San Mateo	104,530	4,635	4.4%
Santa Clara	221,865	4,072	1.8%
Solano	100,720	1,039	1.0%
Sonoma	227,908	3,735	1.6%
	Total Miles	**In Alquist-Priolo Earthquake Fault Rupture Study Zones**	**% of Miles in Study Zones**
INFRASTRUCTURE:			
Roads	33,021	751	2.3%
Transit	433	5	1.2%
Rail	940	11	1.2%
Pipelines	21,851	411	1.9%
	Total Number	**In Alquist-Priolo Earthquake Fault Rupture Study Zones**	**% of Facilities in Study Zones**
CRITICAL FACILITIES:			
Health Care	840	14	1.7%
Schools	2,805	32	1.1%
Bridges	4,153	101	2.4%
Water Facilities	2,095	113	5.4%
Wastewater Facilities	338	3	0.9%
Cities and Counties	4,195	102	2.4%

See http://quake.abag.ca.gov/mitigation/pickdbh2.html and http://quake.abag.ca.gov/pickcrit2010.html for more information.

Fault surface rupture hazard and exposure of existing critical facilities

- Of the 840 critical health care facilities in the Bay Area, 1.7% are in areas designed as subject to the study requirement of the Alquist-Priolo Earthquake Fault Zoning Act.
- Only 1.1% of the 2,805 public schools are in these areas.
- Of the 6,153 critical facilities owned by cities, counties, water, wastewater, transit, and other special districts, 3.4% are in these areas.

Due to the long-standing nature of the Alquist-Priolo Earthquake Fault Zoning Act, few of these facilities are actually located astride faults. They have been rebuilt off the fault, and no new facilities have been built on the fault since the early 1970s when the law went into effect.

Of greater concern than a facility actually being astride a fault, however, is that the fault rupture will impede access and the functioning of infrastructure service to those facilities.
These percentages are based on information in ***Table 6:*** *Surface Rupture Hazard and Existing Land Use*. See ***Plate 1*** and http://quake.abag.ca.gov/mitigation/pickcrit2010.html for more specific information for individual counties and cities.

Shaking hazard and exposure of existing land use

Rather than perform this analysis for each of the many earthquake scenarios developed by USGS and ABAG, we have used the shaking potential map (***Plate 21***) described earlier.

- Of the 4.39 million acres of land in the Bay Area, 80% is exposed to high shaking levels (peak accelerations of greater than 40% of gravity [g] with a 10% chance of being exceeded in the next 50 years), and 37% is exposed to extremely high shaking levels (>60% g).
- 92% of the urban land exposed to high shaking levels (>40% g), and 75% is exposed to extremely high shaking levels (>60% g), while 75% of the non-urban land is exposed to high shaking levels (>40% g), and 38% is exposed to extremely high shaking levels (>60% g). Thus, urban land is exposed to significantly higher shaking hazard than non-urban land.
- Types of existing urban land uses with the highest percentages exposed to extremely high shaking levels (>60% g) are mixed commercial-industrial complexes (88.6%), mixed residential-commercial (71.9%).
- The percentage of urban land exposed to extremely high shaking levels (>60% g) ranged from a high of over 75% in Alameda, San Francisco, San Mateo, and Santa Clara counties to lows of less than 7% in Napa and Solano counties.

These percentages also are based on information in ***Table 7:*** *Shaking Hazard and Existing Land Use*. See ***Plate 21*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Shaking hazard and exposure of existing infrastructure

Rather than perform this analysis for each of the many earthquake scenarios developed by USGS and ABAG, this MJ-LHMP uses the shaking potential map (***Plate 21***) described earlier.

TABLE 7 – Shaking Potential and Existing (2005) Land Use

	Total Acres	Highest Shaking Potential (<80% g)	Next to Highest Shaking Potential (60-80%g)	Middle Category of Shaking Potential (40-60% g)	% of Land in Extreme Shaking Potential	% of Land in Very High or Extreme Shaking Potential
Total	4,387,602	356,083	1,273,510	1,865,773	37.1%	79.7%
Urban	1,139,000	122,485	506,799	423,465	55.2%	92.4%
Non-Urban	3,248,602	233,598	766,711	1,442,309	30.8%	75.2%
URBAN ONLY:						
Residential	555,463	51,099	240,318	224,387	52.5%	92.9%
Mixed R+C	1,775	401	876	461	71.9%	97.9%
Commercial/ Services	110,502	12,922	58,778	32,999	64.9%	94.7%
Mixed C+I	3,344	819	2,144	237	88.6%	95.7%
Industrial	72,125	6,577	36,796	23,403	60.1%	92.6%
Military	30,549	4,981	4,729	17,758	31.8%	89.9%
Infrastructure	205,807	25,351	100,912	61,840	61.4%	91.4%
Urban Open	159,435	20,335	62,245	62,380	51.8%	90.9%
URBAN ONLY:						
Alameda	180,056	27,395	116,255	32,784	79.8%	98.0%
Contra Costa	184,775	7,538	72,201	91,188	43.2%	92.5%
Marin	54,146	9,170	13,357	31,136	41.6%	99.1%
Napa	35,727	119	957	21,157	3.0%	62.2%
San Francisco	29,273	9,106	14,092	5,306	79.2%	97.4%
San Mateo	104,530	37,613	55,887	7,367	89.4%	96.5%
Santa Clara	221,865	9,376	161,297	50,551	76.9%	99.7%
Solano	100,720	3,153	3,235	59,339	6.3%	65.3%
Sonoma	227,908	19,014	69,517	124,636	38.8%	93.5%
	Total Miles	Highest Shaking Potential (<80% g)	Next to Highest Shaking Potential (60-80%g)	Middle Category of Shaking Potential (40-60% g)	% of Miles in Extreme Shaking Potential	% of Miles in Very High or Extreme Shaking Potential
INFRASTRUCTURE:						
Roads	33,021	3,614	15,550	11,294	58.0%	92.2%
Transit	433	84	249	70	76.9%	93.1%
Rail	940	152	394	324	58.1%	92.6%
Pipelines	21,851	2,465	11,258	7,085	62.8%	95.2%
	Total Number	Highest Shaking Potential (<80% g)	Next to Highest Shaking Potential (60-80%g)	Middle Category of Shaking Potential (40-60% g)	% Facilities in Extreme Shaking Potential	% Facilities in Very High or Extreme Shaking Potential
CRITICAL FACILITIES:						
Health Care	840	142	489	193	75.1%	98.1%
Schools	2,805	378	1,541	817	68.4%	97.5%
Bridges	4,153	512	2,198	1,210	65.3%	94.4%
Water Facilities	2,095	244	1,183	530	68.1%	93.4%
Wastewater Fac.	338	49	179	72	67.5%	88.8%
Cities & Counties	4,195	627	2,450	910	73.3%	95.0%

See http://quake.abag.ca.gov/mitigation/pickdbh2.html and http://quake.abag.ca.gov/pickcrit2010.html for more information.

- 93.1% of the fixed transit in the Bay Area is exposed to extremely high or very high shaking potential (>40%g), including 85.5% of ACE, 84.8% of Amtrak, 97% of BART, 100% of Caltrain, 100% of SF MTA (MUNI), and 100% of the VTA lines. This finding on exposure is consistent with the BART effort to upgrade and strengthen its facilities.
- In comparison, 92.2% of the miles of roads, 92.6% of the rail lines, and 95.2% of the pipelines are in these areas.

These percentages are based on information in ***Table 7:*** *Shaking Hazard and Existing Land Use*. See ***Plate 21*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Shaking hazard and exposure of existing critical facilities

Rather than perform this analysis for each of the many earthquake scenarios developed by USGS and ABAG, we have used the shaking potential map (***Plate 21***) described earlier.

- Of the 840 critical health care facilities in the Bay Area, over three-quarters (75.1%) are exposed to extremely high shaking potential (>60%g).
- In addition, 68.4% of the 2,805 public schools are exposed to extremely high shaking potential (>60%g).
- Of the 6,153 critical facilities owned by owned by cities, counties, and other special districts in the Bay Area, 73.2% are exposed to extremely high shaking potential (>60%g).

These vulnerabilities show the need for more detailed risk assessment of these critical facilities, as addressed in the mitigation strategies and described in Chapter 6 – Education and Chapter 5 – Government. Many of these facilities have been seismically retrofitted or will require seismic retrofitting. These percentages are based on information in ***Table 7:*** *Shaking Hazard and Existing Land Use*. See ***Plate 21*** and http://quake.abag.ca.gov/mitigation/pickcrit2010.html for more specific information for individual counties and cities.

Liquefaction susceptibility and exposure of existing land use

Rather than perform this analysis for each of the earthquake scenarios developed by USGS and ABAG, we used the liquefaction susceptibility map (***Plate 22***) described earlier. The areas mapped as having moderate, high, and very high liquefaction susceptibility are roughly equivalent to the areas mapped by CGS as areas where studies are required (***Plate 23***).

- Of the 4.39 million acres of land in the Bay Area, 2.2% is in areas mapped as having very high liquefaction susceptibility, while 23.8% is the areas mapped in the combined moderate-high-very high liquefaction susceptibility category.
- 5.6% of the urban land is in the areas mapped as having very high liquefaction susceptibility, versus only 1.0% of the non-urban land.
- 42.4% of the urban land is in the areas mapped in the combined moderate-high-very high liquefaction susceptibility category, versus only 17.3% of the non-urban land.
- Types of existing urban land uses with the highest percentages in those areas mapped as having very high liquefaction susceptibility are mixed commercial-industrial complexes (17.8%), military use (15.1%), and industrial (11.3%).

TABLE 8 – Liquefaction Susceptibility and Existing (2005) Land Use

	Total Acres	Very High Liquefaction Susceptibility	High Liquefaction Susceptibility	Moderate Liquefaction Susceptibility	% in Very High	% in High	% in Moderate
Total	4,387,602	95,428	205,262	744,293	2.2%	4.7%	17.0%
Urban	1,139,000	64,057	33,252	385,482	5.6%	2.9%	33.8%
Non-Urban	3,248,602	31,370	172,010	358,812	1.0%	5.3%	11.0%
URBAN ONLY:							
Residential	555,463	14,960	12,624	165,964	2.7%	2.3%	29.9%
Mixed R+C	1,775	162	32	714	9.1%	1.8%	40.2%
Commercial/ Services	110,502	7,927	3,184	51,935	7.2%	2.9%	47.0%
Mixed C+I	3,344	595	64	1,817	17.8%	1.9%	54.3%
Industrial	72,125	8,180	2,727	32,542	11.3%	3.8%	45.1%
Military	30,549	4,609	1,790	7,178	15.1%	5.9%	23.5%
Infrastructure	205,807	17,454	7,559	84,199	8.5%	3.7%	40.9%
Urban Open	159,435	10,169	5,272	41,133	6.4%	3.3%	25.8%
URBAN ONLY:							
Alameda	180,056	16,414	7,921	86,626	9.1%	4.4%	48.1%
Contra Costa	184,775	5,483	5,923	46,049	3.0%	3.2%	24.9%
Marin	54,146	5,811	643	10,926	10.7%	1.2%	20.2%
Napa	35,727	1,002	712	11,454	2.8%	2.0%	32.1%
San Francisco	29,273	5,044	228	10,155	17.2%	0.8%	34.7%
San Mateo	104,530	13,515	1,177	20,881	12.9%	1.1%	20.0%
Santa Clara	221,865	5,913	7,269	114,829	2.7%	3.3%	51.8%
Solano	100,720	5,827	3,743	31,414	5.8%	3.7%	31.2%
Sonoma	227,908	4,179	4,765	46,826	1.8%	2.1%	20.5%
	Total Miles	**Very High Liquefaction Susceptibility**	**High Liquefaction Susceptibility**	**Moderate Liquefaction Susceptibility**	**% in Very High**	**% in High**	**% in Moderate**
INFRASTRUCTURE:							
Roads	33,021	1,820	1,282	13,004	5.5%	3.9%	39.4%
Transit	433	51	9	240	11.8%	2.1%	55.4%
Rail	940	150	48	443	16.0%	5.1%	47.1%
Pipelines	21,851	1,286	558	9,816	5.9%	2.6%	44.9%
	Total Number	**Very High Liquefaction Susceptibility**	**High Liquefaction Susceptibility**	**Moderate Liquefaction Susceptibility**	**% in Very High**	**% in High**	**% in Moderate**
CRITICAL FACILITIES:							
Health Care	840	61	6	481	7.3%	0.7%	57.3%
Schools	2,805	130	44	1,477	4.6%	1.6%	52.7%
Bridges	4,153	404	204	1,986	9.7%	4.9%	47.8%
Water Facilities	2,095	114	20	531	5.4%	1.0%	25.3%
Wastewater Facilities	338	121	23	72	35.8%	6.8%	21.3%
Cities & Counties	4,195	610	178	1,864	14.5%	4.2%	44.4%

See http://quake.abag.ca.gov/mitigation/pickdbh2.html and http://quake.abag.ca.gov/pickcrit2010.html for more information.

- The percentage of urban land located in these areas mapped as having very high liquefaction susceptibility ranged from a high of 17.2% in San Francisco to lows of less than 6% in Contra Costa, Napa, Santa Clara, Solano, and Sonoma counties.

These percentages are based on information in ***Table 8:** Liquefaction Susceptibility and Existing Land Use*. See ***Plate 22*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Liquefaction susceptibility and exposure of existing infrastructure

Again, we have used the liquefaction susceptibility map (***Plate 22***) described earlier.

- Of the 33,021 miles of roads in the Bay Area, 5.5% are in areas mapped as having very high liquefaction susceptibility, while 48.8% are the areas mapped in the combined moderate-high-very high liquefaction susceptibility category.
- In comparison, 16% of the miles of rail, 11.8% of transit lines (1.8% of ACE, 20.2% of Amtrak, 7.9% of BART, 10.4% of Caltrain, 24.3% of SF MTA (MUNI), and 2.4% of the VTA lines). Finally, 5.9% of pipelines are in the very high liquefaction susceptibility category. These exposures are of concern because of the potential vulnerability of these lines to damage.

These percentages are based on information in ***Table 8:** Liquefaction Susceptibility and Existing Land Use*. See ***Plate 22*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Liquefaction susceptibility and exposure of existing critical facilities

Again, we have used the liquefaction susceptibility map (***Plate 22***) described earlier.

- Of the 840 critical health care facilities in the Bay Area, 7.3% are in areas mapped as having very high liquefaction susceptibility, while 65.2% are the areas mapped in the combined moderate-high-very high liquefaction susceptibility category.
- Of the 2,805 public schools in the Bay Area, 4.6% are in areas mapped as having very high liquefaction susceptibility, while 58.9% are the areas mapped in the combined moderate-high-very high liquefaction susceptibility category.
- Of the 6,153 critical facilities owned by cities, counties, and other districts, 12.7% are in areas mapped as having very high liquefaction susceptibility, while 55.0% are the areas mapped in the combined moderate-high-very high liquefaction susceptibility category.

These percentages are based on information in *Table 8: Liquefaction Susceptibility and Existing Land Use*. See ***Plate 22*** and http://quake.abag.ca.gov/mitigation/pickcrit2010.html for more specific information for individual counties and cities.

Earthquake-induced landslide susceptibility and exposure of existing land use, infrastructure, and critical facilities

The best available map for showing earthquake-induced landslide susceptibility is the one prepared by CGS showing the areas where studies are required (***Plate 42***). The problem with any type of regional assessment using this map is that it does not cover the entire Bay Area. Thus, while the database of exposed land uses exists at http://quake.abag.ca.gov/mitigation/pickdbh2.html, the data for the region does not exist in a format for a regional analysis. However, in areas where this mapping has not been completed, the rainfall-induced landslide hazard map is an acceptable substitute. The hazard exposure for this mapping is described in the "Weather" section of this Appendix.

Vulnerability of the Bay Area to earthquake hazards

Uninhabitable housing due to earthquake ground shaking damage

ABAG has been modeling uninhabitable housing units and resulting shelter populations beginning shortly after the Loma Prieta earthquake with a contract with the Bay Area Chapter of the American Red Cross. This initial effort was expanded and improved with three separate grants from the National Science Foundation and the U.S. Geological Survey.

The models use estimates of numbers of older single family homes, mobile homes, soft-story multifamily buildings, unreinforced masonry buildings, and other vulnerable housing types, the locations of those structures, shaking exposure, and damage data from past earthquakes to create estimates of uninhabitable housing units for the region. Although the models produce estimates by census tract and city, the models lose accuracy as the modeled area becomes smaller.

The 1989 Loma Prieta earthquake caused a total of over 16,700 units to be uninhabitable throughout the Monterey and San Francisco Bay Areas (including almost 13,000 in the Bay Area). As shown in ***Table 9***: *Predicted Uninhabitable Units for Bay Area Counties and Selected Earthquake Scenarios*, thirteen of 18 potential Bay Area earthquakes analyzed are expected to have a far larger impact than the Loma Prieta earthquake. In fact, *eight* of these earthquakes will probably have a greater impact than the 1994 Northridge earthquake in the Los Angeles area, where over 46,000 housing units were made uninhabitable. See http://www.abag.ca.gov/bayarea/eqmaps/eqhouse.html for additional information.

TABLE 9 – Predicted Uninhabitable Units for Bay Area Counties and Selected Earthquake Scenarios

Earthquake Scenario	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Santa Cruz Mts. San Andreas	1,968	159	297	0	11,781	223	1,277	2	3	15,710
Peninsula-Golden Gate San Andreas	3,820	188	1,485	3	65,316	22,525	15,094	11	42	108,484
Northern Golden Gate San Andreas	4,345	560	2,988	19	62,654	1,904	449	127	1,804	74,851
Entire Bay Area San Andreas	16,048	1,173	3,495	20	82,354	24,472	29,593	185	2,530	159,870
No. San Gregorio	3,104	238	1,176	4	38,306	9,040	589	12	45	52,514
So. Hayward	64,451	1,760	1,030	16	13,940	245	11,892	126	37	93,497
No. Hayward	43,132	7,686	1,653	19	11,464	210	303	128	74	64,669
N + S Hayward	88,265	10,102	2,125	36	37,670	1,616	14,273	1,046	559	155,692
Rodgers Creek	3,688	1,418	1,549	53	11,460	151	100	1,148	13,988	33,555
Rodgers Creek-No. Hayward	49,284	9,786	2,691	713	29,758	363	402	1,386	14,115	108,498
So. Maacama	325	17	27	22	1,986	11	11	15	825	3,239
West Napa	1,382	286	27	4,284	2,011	15	29	1,668	126	9,828
Concord-Green Valley	3,511	11,363	29	1,307	3,191	76	325	2,868	37	22,707
No. Calaveras	7,836	3,509	27	18	3,191	78	4,882	181	6	19,728
Central Calaveras	3,037	75	27	3	3,191	182	10,145	13	4	16,677
Mt. Diablo	6,128	4,868	751	3	10,489	23	109	17	4	22,392
Greenville	2,701	2,637	27	19	2,005	16	101	190	6	7,701
Monte Vista	323	5	16	1	2,429	2,392	27,223	2	2	32,393

TABLE NOTES – This table is based on ABAG's modeling of uninhabitable housing units in future earthquake scenarios ***(Shaken Awake!,*** Perkins and others, 1996) that was last updated in 2003 for consistency with U.S. Geological Survey earthquake scenarios of 2003 as well as 2008. This modeling is based on an extensive statistical analysis of the housing damage which occurred as a result of the 1989 Loma Prieta and 1994 Northridge earthquakes. However, the expected percentage of pre-1940 single-family homes rendered uninhabitable used to generate this table is larger than published in 1996. New data on lack of retrofitting and reasons for low damage in the Northridge earthquake caused ABAG to increase the uninhabitable percentages used to create this table for pre-1940 single-family homes to 19% and 25% for MMI IX and X, respectively.

Note that several fault segments listed above have new segment end points or were not included in the 1996 report. They are included in this table to reflect ground shaking information published by USGS in 2003. The Santa Cruz Mts.–San Andreas is similar, but not identical, to the fault causing the Loma Prieta earthquake. The Monte Vista and West Napa faults have been added to the faults analyzed by USGS to illustrate the impact of an earthquake in these areas. The Maacama fault could impact the North Bay, but too little was known about the fault for the USGS to issue probabilities for it in 2003. It, too, has been added to illustrate possible damage. On the other hand, the Southern Calaveras, the Southern San Gregorio, and the northern North Coast–San Andreas faults are outside of the Bay Area. The Bay Area impacts of earthquakes on these fault segments are dwarfed by their Bay Area segments so they are not included. Additional information on earthquakes and housing is available in ***Shaken Awake!*** and on the ABAG Earthquake Program Internet site at http://quake.abag.ca.gov.

Transportation system disruption due to earthquakes

ABAG has been modeling road closures beginning in 1994 with a grant from Caltrans. This initial effort was expanded with additional funding from a grant from the U.S. Geological Survey.

The models separately calculate the number of road closures from a variety of sources: fault rupture, liquefaction, earthquake-triggered landslides, shaking damage to bridges and highway structures, as well as indirect causes of closures such as building damage, hazmat releases, and utility pipeline breaks. The models are based on the locations of roads and transportation structures, shaking exposure, and hazard maps of faults, slides, and liquefaction, locations of buildings that might fall to close roads, sources of hazmat releases, and pipeline locations, as well as damage data from past earthquakes. Although the models produce estimates by census tract and city, the models lose accuracy as the modeled area becomes smaller.

The 1989 Loma Prieta earthquake caused a total of only 142 road closures throughout the Monterey and San Francisco Bay Areas, whereas the Northridge earthquake resulted in only 140 road closures.

As shown in ***Table 10***: *Predicted Road Closures for Bay Area Counties and Selected Earthquake Scenarios*, 16 of 18 potential Bay Area earthquakes analyzed are expected to have a far larger impact than either the Loma Prieta or the Northridge earthquake. In fact, ***five*** of these earthquakes are predicted to have over 1,000 road closures. One of the major causes of potential road and transit closures is BART.
See http://www.abag.ca.gov/bayarea/eqmaps/eqtrans/eqtrans.html for additional information.

TABLE 10 – Predicted Road Closures for Bay Area Counties and Selected Earthquake Scenarios

Earthquake Scenario	Alameda	Contra Costa	Marin	Napa	San Francisco	San Mateo	Santa Clara	Solano	Sonoma	TOTAL
Santa Cruz Mts. San Andreas	24	10	3	0	44	9	64	0	1	154
Peninsula-Golden Gate San Andreas	50	9	22	0	335	300	146	1	4	866
Northern Golden Gate San Andreas	62	20	70	1	321	24	10	4	69	581
Entire Bay Area San Andreas	146	30	77	3	429	315	250	6	75	1,332
No. San Gregorio	43	11	20	0	164	144	13	1	6	401
So. Hayward	901	43	15	1	72	8	90	4	4	1,138
No. Hayward	335	238	20	1	48	5	7	5	8	667
N + S Hayward	1,081	268	28	2	214	16	99	10	16	1,734
Rodgers Creek	54	34	20	4	48	3	3	12	223	4
Rodgers Creek-No. Hayward	363	256	34	9	157	11	10	14	230	1,084
So. Maacama	8	3	1	3	6	0	1	1	53	74
West Napa	22	20	1	89	6	1	1	14	5	159
Concord-Green Valley	56	201	1	19	11	3	7	83	4	386
No. Calaveras	180	107	1	1	11	3	53	6	1	363
Central Calaveras	51	10	1	0	11	4	132	1	1	210
Mt. Diablo	94	78	7	0	41	2	4	2	1	228
Greenville	70	47	1	1	6	1	4	6	1	138
Monte Vista	10	1	0	0	8	23	283	0	1	326

TABLE NOTES – This table is based on ABAG's modeling of road closures in future earthquake scenarios ***(Riding Out Future Quakes,*** Perkins and others, 1997) that was last updated in 2003 for consistency with U.S. Geological Survey earthquake scenarios of 2003 as well as 2008. This modeling is based on an extensive statistical analysis of the road closures which occurred as a result of the 1989 Loma Prieta and 1994 Northridge earthquakes.

Note that several fault segments listed above have new segment end points or were not included in the 1996 report. They are included in this table to reflect ground shaking information published by USGS in 2003. The Santa Cruz Mts.–San Andreas is similar, but not identical, to the fault causing the Loma Prieta earthquake. The Monte Vista and West Napa faults have been added to the faults analyzed by USGS to illustrate the impact of an earthquake in these areas. The Maacama fault could impact the North Bay, but too little was known about the fault for the USGS to issue probabilities for it in 2003. It, too, has been added to illustrate possible damage. On the other hand, the Southern Calaveras, the Southern San Gregorio, and the northern North Coast–San Andreas faults are outside of the Bay Area. The Bay Area impacts of earthquakes on these fault segments are dwarfed by their Bay Area segments so they are not included. Additional information on earthquakes and housing is available in ***Riding Out Future Quakes*** and on the ABAG Earthquake Program Internet site at http://quake.abag.ca.gov.

Water and wastewater system disruption due to earthquakes

Pipelines break and leak as a result of earthquakes. An ABAG analysis of damaged pipelines following the 1989 Loma Prieta earthquake indicated that pipelines in areas subject to liquefaction AND exposed to violent ground shaking were the most likely to have broken or leaked as a result of that earthquake.

In 2009, ABAG re-estimated the number of kilometers (and miles) of water distribution pipeline based on assuming that all roads within a water supply retailer's service area are underlain by a pipeline. (In the previous research performed by ABAG (Perkins and others, 2001), all roads were assumed to be underlain by a pipeline, which led to an overestimation of the number of kilometers of water distribution pipeline.)

TABLE 11 – Data on Number of Water Pipeline Breaks or Leaks from Past Earthquakes

Shaking		O'Rourke Northridge Data*		1991	ABAG Loma Prieta Data vs. Liquefaction Susc.			
Intensity	PGV	Brittle Pipe	Flexible Pipe	Eguchi	Total	Very High	High-Mod.	Low-Very Low
1 - V	6	0.010	0.013	0	0.001	0	0	0.001
2 - VI	13	0.025	0.030	0.003	0.005	0.013	0.005	0.005
3 - VII	30	0.070	0.072	0.03	0.026	0.084	0.022	0.021
4 - VIII	61	0.164	0.152	0.3	0.182	0.386	0.064	0.05
5 - IX	130	0.411	0.337	0.4	n/a	n/a	n/a	n/a
6 - X	286	1.066	0.770	1.2	n/a	n/a	n/a	n/a

*Note: O'Rourke data for MMI IX and X is based on statistical regressions in his research, not on published data.

In addition, in 2009, ABAG has re-calculated the number of pipeline breaks associated with the Loma Prieta earthquake based on the 2006 liquefaction susceptibility mapping (Witter and others, 2006 versus the earlier Knudsen and others, 2000, mapping). The following table compares the number of pipeline breaks based on Eguchi (1991), Jeon and O'Rourke (2005), and ABAG (Perkins, 2001, updated 2009).

Based on pipeline repair rates determined by ABAG in the 1989 Loma Prieta earthquake, including damage due to shaking, liquefaction, landsliding, and fault rupture, the number of pipeline repairs would be approximately 6,000 in an earthquake on the Hayward fault (compared to 507 in the Loma Prieta earthquake). However, some pipeline materials, such as concrete asbestos and cast iron, are significantly more prone to breaking and leaking. In addition, if the earthquake occurs in the winter when the ground is saturated, many more repairs will be necessary than during the dry conditions present during the October Loma Prieta event or the extremely dry January Northridge event. These changes could increase the number of estimated repairs to 10,000 or more. Thus, the estimate for water pipeline repairs in a large Hayward fault earthquake is 6,000 to 10,000. This range is consistent with system-specific engineering evaluations conducted by water suppliers impacted by this East Bay earthquake.

There will be more leaks and breaks in sewer system collection pipelines because these pipes are more brittle.

Rapid repair and replacement of water and sewer pipelines is essential to recovery from an earthquake.
The various approaches to mitigation of water and wastewater system disruption are described in Chapter 1 - Infrastructure. EBMUD, CCWD, and Santa Clara Valley Water District have

installed, and SFPUC and Alameda County Water District are in the process of installing, shut-off valves in pipelines that cross active faults. These valves, installed on each side of the fault, enable above-ground potable water bypass lines to be rapidly installed.

The pipeline distribution systems for water and sewer lines typically have not been replaced since they were originally installed, in some cases almost 100 years ago. These pipelines will break and leak. Ways to mitigate this damage through repair and replacement of the most susceptible lines has started, but will not be completed for many years. Some water suppliers have also purchased equipment to bag water for customers if pipelines are broken.

Assessment of options for earthquake loss estimation

The 1994 Northridge earthquake caused over $40 billion in losses, while the 1989 Loma Prieta earthquake caused about $6 billion in losses.

ABAG collaborated with USGS, CGS, and OES to write a 2003 paper on the results of several HAZUS[8] runs for earthquake-related losses associated with future scenario earthquakes. ABAG staff identified several potentially significant problems with using a combination of ShakeMap scenarios (which, as explained earlier, tend to produce shaking levels lower than the ABAG Shaking Scenario maps), the existing vulnerability formulas (which are prone to underestimate housing losses and losses to wood-frame structures such as dominate the building stock in the Bay Area), and incomplete building inventory data. *These HAZUS loss estimates are inadequate for planning purposes at the present time.* See http://quake.abag.ca.gov/mitigation/HAZUS_Paper.pdf for the entire paper.

Risk Management Solutions (RMS), a private corporation which produces loss estimates for the insurance industries, prepared a loss estimate for a repeat of the 1868 Hayward earthquake (2008). The RMS estimate for housing-related losses alone totaled $90 billion, of which only $4.4 billion would be covered by earthquake insurance. In comparison, the HAZUS estimate for building losses from ALL sources (just part of which was residential) for this same earthquake was only $8 billion!

Earthquake Impacts

The natural disasters with the largest potential impacts on the Bay Area are earthquakes. Most of the damage is due to ground shaking, with relatively little due to liquefaction and landsliding. For example, in the Loma Prieta earthquake, only 1.6% of the $6 billion in losses could be attributed to liquefaction[9], and an even smaller percentage to landsliding. Surface fault rupture can do significant damage to infrastructure systems, depending on the earthquake. (The fault that caused the Loma Prieta earthquake, for example, did not rupture the surface, so there were no losses associated with fault rupture in that earthquake.)

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[8] HAZUS is a software package developed by FEMA for loss modeling.

[9] Holzer, T.L., ed., 1998. "Introduction" in ***The Loma Prieta, California, Earthquake of October 17, 1989 – Liquefaction.*** U.S. Geological Survey Prof. Paper 1551-B: Reston, VA, pp. B4.

The extent of the impact of earthquake disasters can best be explained using various earthquake scenario events. For example, in a magnitude 6.9 earthquake on the entire Hayward fault (extending from San Pablo Bay to the border of Alameda and Santa Clara counties), ABAG has estimated over 150,000 uninhabitable housing units and 1,700 road closures. In 2003, the FEMA-developed HAZUS software only estimated 24,000 displaced households, a factor of 6 lower than the ABAG estimates. Part of this discrepancy is due to uncertainty on the impact on wood-frame apartments with parking in the ground floor ("soft-story" apartments). HAZUS estimates the total losses for that earthquake as only $23 billion (versus actual losses of over $40 billion in the Northridge earthquake, a smaller magnitude earthquake with a less vulnerable building stock). The Bay Area Economic Forum produced a 2002 report on the impact of this earthquake on *Hetch-Hetchy Water and the Bay Area Economy*[10], estimating that the losses associated with failure of that system alone would be $17.2 billion. Finally, the HAZUS software predicts from 100-700 fatalities in that earthquake scenario, depending on the time of day. These estimates are difficult to evaluate, particularly because they are so tied to the vulnerability of particular systems. For example, fatalities in the BART tube alone could exceed that value if the tube were to rupture catastrophically. Obviously, the current HAZUS estimates are inadequate.

Thus, ABAG will be working to develop different ways to either refine those estimates or develop alternative ways to express losses and risk. As mentioned earlier, RMS proprietary software used to estimate residential losses produced an estimate of $90 billion given a repeat of the 1868 Hayward earthquake on the southern Hayward fault in 2008, versus an estimate of only $8 billion from the 2003 HAZUS run. This MJ-LHMP estimates that the RMS estimate is much closer to reality. See ABAG mitigation strategy GOVT-e-2. Any remaining gaps in knowledge following that effort will be identified as part of that effort. The goal is for future loss estimates to be city-specific. Interestingly, the final report conducted by ABAG for the City of Oakland on soft-story housing in Oakland focused not on dollar damage losses, but on issues of habitability and community-level impacts, such as loss of property tax and business tax, for these data were more valuable than estimated dollar losses.

Additional earthquake risk assessment plans

ABAG is continually examining options for improving risk assessments over time, such as risk assessments on privately-owned hazardous buildings in earthquakes. The results of these risk assessments are incorporated into the applicable chapters of the MJ-LHMP as this plan is updated over time. Some of the initial results of that effort are described in Chapter 3 – Housing and Chapter 4 – Economy.

ABAG has completed a preliminary assessment of soft story multi-family buildings in Oakland. A survey conducted by volunteers looked for percent openness on three sides of the buildings as could be viewed from the street. The buildings all contained 5 more units, we at least 2 stories tall and believed to be built before 1990. Volunteers surveyed a total of 2,908 buildings meeting these criteria. 1,479 buildings were determined to be suspicious soft story buildings. Soft story buildings will contribute to a significant number of injuries and displaced people following a major earthquake. The city of Oakland is in the process of developing a program to evaluate each of these buildings more thoroughly and order an engineered evaluation for those determined to

[10] See http://www.bayeconfor.org/pdf/hetchhetchyfinal2.pdf to view the entire report.

be likely soft story buildings. Berkeley, San Francisco, Santa Clara County, Alameda and San Leandro are in various staging of evaluating their soft story building stock and mandating evaluations or retrofits.

Tsunamis

Probability of tsunami-related hazards

Large underwater displacements from major earthquake fault ruptures or underwater landslides can lead to ocean waves called tsunamis.[11] Since tsunamis have high velocities, the damage from a particular level of inundation is far greater than with a normal flood event.

Tsunamis can result from off-shore earthquakes within the Bay Area, or from distant events. While it is most common for tsunamis to be generated by subduction faults such as those in Washington and Alaska, local tsunamis can be generated from strike-slip faults. The San Andreas fault runs along the coast off the Peninsula and the Hayward fault runs partially through San Pablo Bay.

The existing CalEMA tsunami maps are not officially a hazard map, but an evacuation planning map, because it is not based on probabilities. The *Purpose of the Map* section on the 2009 CalEMA maps notes:

> The inundation map has been compiled with best currently available scientific information. The inundation line represents the maximum considered tsunami run-up from a number of extreme, yet realistic, tsunami sources. Tsunamis are rare events; due to a lack of known occurrences in the historical record, this map includes no information about the probability of any tsunami affecting any area within a specific period of time.

It is not sufficient to estimate the probability of future tsunamis simply based on past occurrences. Because tsunamis are rare there is not enough data in the historical record to adequately derive a return period. The method for conducting probabilistic tsunami hazard analysis and a return period will involve extensive work over the next several years and will incorporate modeled tsunamis from all over the Pacific Rim.

As of June 2010, a team is just beginning to meet to discuss the best scientific methodology, appropriate data and scoping needed to move this work forward under the guidance of CGS who has the legislative mandate to perform this work. Discussion revolves around properly defining seismic sources, determining realistic fault parameters, and determining what various return periods will be.

Because not all off shore earthquakes will trigger tsunamis and not all tsunamis will affect a particular location, it is not appropriate to simply relate probability of tsunami to earthquake probabilities. ABAG and the jurisdictions covered under this LHMP will use the new probability information and associated maps in its mitigation planning efforts when they become available.

Location and extent of tsunami-related hazards

In December 2010, new evacuation planning maps showing the entire Bay Area ocean and inner bay coastline (except for northern Sonoma County) have been released as part of a CalEMA-led effort. This map is a worst-case scenario map that aggregates all the potential sources of tsunamis and measures the highest potential wave height from any tsunami event at each location

[11] Waves in enclosed bodies, such as lakes or Bays, are called *seiches*. There are no published maps or hazard information on seiche hazards in the Bay Area.

along the coast. The inundation was ground-truthed to account for development that might impede inundation. The map is ***Plate 43** – Tsunami Evacuation Planning Areas*. As with the other maps, more detailed maps for individual local governments, and additional tsunami hazard information is available at http://quake.abag.ca.gov/tsunami.

Tsunami mitigation strategies are limited due to the lack of hazard maps and include evacuation planning (GOVT c-24) and cooperation to increase the speed of completion of hazard maps (GOVT-d-10).

Past occurrences of Bay Area tsunami -related disasters

Tsunamis have not been a major problem in the Bay Area. In 1859 a tsunami generated by an earthquake in Northern California generated 4.6 m wave heights near Half Moon Bay. The Great 1868 earthquake on the Hayward fault is reported to have created a local tsunami in the San Francisco Bay. In the same year a magnitude 8.5 earthquake off the coast of Chile caused 1.8 m wave heights near San Pedro. In 1960 Pacific experienced high water resulting from a magnitude 9.5 off the coast of Chile. The tsunami generated by the 1964 Alaskan earthquake caused wave heights of three to seven meters off the Coast of Northern California, Oregon and Washington. Eleven people were killed in Crescent City as a result of this tsunami. Along the coast of San Francisco, Marin and Sonoma Counties, maximum wave heights of 1.1 meters were recorded and no significant damage was experienced.

Damage from all of these tsunamis has been virtually non-existent and data are extremely limited. A complete historical list of tsunamis affecting the California Coast is available at http://www.consrv.ca.gov/cgs/geologic_hazards/tsunami/pages/about_tsunamis.aspx.

Exposure and vulnerability of the Bay Area to tsunami hazards

ABAG has not performed any analysis of the land use and infrastructure exposure within the tsunami evacuation areas as part of this multi-jurisdictional Local Hazard Mitigation Plan. This exposure data is also not available on ABAG's internet site. While the tsunami evacuation planning maps released by CalEMA in December 2009 cover the Bay Area's coastline (except for northern Sonoma County) and inside the Bay, CalEMA has stressed that these maps are NOT appropriate for anything but evacuation planning.

Only exposure information for locally owned critical facilities will become available on ABAG's website. It is not appropriate to evaluate infrastructure or land use against the current tsunami maps because they are evacuation planning maps only, not hazard maps.

Tsunamis and exposure of existing critical facilities

- Of the 840 critical health care facilities in the Bay Area, none are within the tsunami inundation zone
- Of the 2,805 public schools in the Bay Area, two are within the tsunami inundation zone
- Of the 4,153 bridges in the Bay Area, 85 are within the tsunami inundation zone
- Of the 6,153 critical facilities owned by cities, counties, and other districts, 365 are within the tsunami inundation zone

- 36 of the 2,095 water facilities (1.7%) and 54 of the 338 wastewater facilities (16%) are within the tsunami inundation zone.

See ***Plate 43*** and http://quake.abag.ca.gov/mitigation/pickcrit2010.html for more specific information for individual counties and cities.

When hazard maps are released by CGS and CalEMA in one to two years, then it will be appropriate for ABAG and the other local governments in the Bay Area to use these maps in ways similar to the other earthquake hazard maps described in this Appendix.

Flooding

Flooding probabilities, location, and extent

The Federal Emergency Management Agency (FEMA) has mapped *flooding* hazards in the Bay Area's low-lying areas. These flood hazard maps have built-in probability information – the 100-year floodplain or the 500-year floodplain. ***Plate 44*** depicts the 100-year flood zone for the Bay Area, as well as the zone for 500-year floods and other concerns. In general, these maps are based on the updated and improved FEMA digital Flood Insurance Rate Maps (D-FIRMs). However, as of June 2010, only the older Q3 data were available for San Mateo County. D-FIRMs for San Mateo County are not expected to be released until September 2010.

More detailed maps for individual local governments and additional flood hazard information are available on line at http://www.abag.ca.gov/bayarea/eqmaps/eqfloods/floods.html.

The maps available on the ABAG web site do not include information on depth of flooding, except that the 500-year flood areas also include areas subject to 100-year flood events with flooding depths expected to be less than one foot.

FEMA's National Flood Insurance Program provides insurance to homeowners in declared flood areas. As part of this program FEMA keeps data on repetitive loss properties. These are properties that have submitted claims for flood reimbursement at least twice in the last ten years. The goal of mapping these properties is to identify what locations flood repetitively and seek to mitigate the problem to reduce flood damage. ***Plate 55*** depicts the locations of repetitive loss properties in the Bay Area.

[*Note – flooding associated with tsunami hazards are covered above under earthquake-related hazards, not as part of flooding in this discussion. Similarly, flooding from dam inundation is covered in its own section in this document*]

Past occurrences of Bay Area flood-related disasters

Flooding associated with severe storms has been among the most common disaster in the Bay Area during the period from 1950 to 2010, occurring on average 1.3 times a year over the past 60 years. Often heavy rainfall brings many areas of localized flooding, especially in low lying areas of the region. Many other locally significant floods have occurred during this time period. These floods are described in the jurisdictions' **Annex** to this plan.

Extensive flooding occurred in 1950, 1957, 1958, 1959, 1962, 1963, 1964, 1965, 1966, 1969, 1970, 1973, 1980, 1982, 1983, 1992, 1995, 1996, 1997, 1998, 2005, 2006, and 2008.

See Appendix D and http://quake.abag.ca.gov/mitigation/disaster-history.html for more specific information.

Exposure and vulnerability of the Bay Area to flooding-related disasters

One method of assessing vulnerability is to examine existing land uses in mapped hazard areas. See ***Table 12*** for acres of existing land use within flood plains.

TABLE 12 – Flooding Hazard and Existing (2005) Land Use

	Total Acres	Within 100-Year Flood Zone	Within 500-Year Flood Zone or Other Area of Concern	% of Land Within 100-Year Flood Zone	% of Land Within 500-Year Flood Zone or Other Area of Concern
Total	4,387,602	424,920	153,407	9.7%	3.5%
Urban	1,139,000	72,811	121,688	6.4%	10.7%
Non-Urban	3,248,602	352,109	31,719	10.8%	1.0%
URBAN ONLY:					
Residential	555,463	19,145	53,881	3.4%	9.7%
Mixed R+C	1,775	96	67	5.4%	3.8%
Commercial/ Services	110,502	7,310	19,209	6.6%	17.4%
Mixed C+I	3,344	617	388	18.5%	11.6%
Industrial	72,125	10,797	11,297	15.0%	15.7%
Military	30,549	3,727	274	12.2%	0.9%
Infrastructure	205,807	15,960	26,456	7.8%	12.9%
Urban Open	159,435	15,160	10,116	9.5%	6.3%
URBAN ONLY:					
Alameda	180,056	9,720	12,520	5.4%	7.0%
Contra Costa	184,775	11,724	6,297	6.3%	3.4%
Marin	54,146	5,899	4,038	10.9%	7.5%
Napa	35,727	3,829	624	10.7%	1.7%
San Francisco	29,273	0	0	0.0%	0.0%
San Mateo	104,530	4,946	4,089	4.7%	3.9%
Santa Clara	221,865	14,253	84,448	6.4%	38.1%
Solano	100,720	11,564	6,585	11.5%	6.5%
Sonoma	227,908	10,877	3,086	4.8%	1.4%
	Total Miles	Within 100-Year Flood Zone	Within 500-Year Flood Zone or Other Area of Concern	% of Miles Within 100-Year Flood Zone	% of Miles Within 500-Year Flood Zone or Other Area of Concern
INFRASTRUCTURE:					
Roads	33,021	1,731	3,972	5.2%	12.0%
Transit	433	42	74	9.7%	17.1%
Rail	940	149	117	15.9%	12.4%
Pipelines	21,851	809	3,264	3.7%	14.9%
	Total Number	Within 100-Year Flood Zone	Within 500-Year Flood Zone or Other Area of Concern	% Within 100-Year Flood Zone	% Within 500-Year Flood Zone or Other Area of Concern
CRITICAL FACILITIES:					
Health Care	840	14	137	1.7%	16.3%
Schools	2,805	69	393	2.5%	14.0%
Bridges	4,153	469	638	11.3%	15.3%
Water Facilities	2,095	80	128	3.8%	6.1%
Wastewater Facilities	338	39	26	11.5%	7.7%
Cities & Counties	4,195	309	713	7.4%	17.0 %

See http://quake.abag.ca.gov/mitigation/pickdbh2.html and http://quake.abag.ca.gov/pickcrit2010.html for more information.

Flooding and exposure of existing land use

- Of the 4.39 million acres of land in the Bay Area, 9.7% is in the 100-year flood zone, while only 3.5% is in the 500-year flood zone or area of other flooding concern.
- 6.4 % of the urban land is in the 100-year flood zone, versus 10.8% of the non-urban land.
- 10.7% of the urban land is in the 500-year flood zone or area of other concern, versus only 1.0% of the non-urban land. The fact that over ten times the percentage of urban versus non-urban land is in these areas is because lands protected from 100-year flooding are in these areas of "other flooding concerns."
- Types of existing urban land uses with the highest percentages in 100-year flood zones are mixed commercial-industrial complexes (18.5%), industrial (15%), and military use (12.2%).
- The percentage of urban land located in the 100-year flood zone ranged from a high of 11.5% in Solano County and 10.9% in Marin County to lows of 0% in San Francisco and 4.7% in San Mateo County.

These percentages are based on information in ***Table 11:*** *Flooding Hazards and Existing Land Use*. See ***Plate 44*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Flooding and exposure of existing infrastructure

- Rail is disproportionately located in zones subject to 100-year floods, with 15.9% of the miles of track located in these areas.
- Pipelines, as underground lines, should not be impacted by flooding even though 3.7% of the miles of pipelines in the region are in these areas.
- 9.7% of the transit lines are in these areas, including 14.5% of ACE, 21% of Amtrak, 2% of BART, 6.5% of Caltrain, none of SF MTA (MUNI), and 4.8% of the VTA lines. This statistic points to a need for further assessment on the part of transit operators. For example, underground BART stations are more vulnerable to potential flooding than are elevated track.

These percentages are based on information in ***Table 11:*** *Flooding Hazards and Existing Land Use*. See ***Plate 44*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Flooding and exposure of existing critical facilities

- Of the 840 critical health care facilities in the Bay Area, 1.7% are in zones subject to 100-year floods.
- Of the 2,805 public schools in the Bay Area, 2.5% are in zones subject to 100-year floods.
- Of the 6,153 critical facilities owned by cities, counties, and other districts, 6.7% are in zones subject to 100-year floods.

These percentages are based on information in ***Table 11:*** *Flooding Hazards and Existing Land Use*. See ***Plate 44*** and http://quake.abag.ca.gov/mitigation/pickcrit2010.html for more specific information for individual counties and cities.

Repetitive flood losses

The Federal Emergency Management Agency (FEMA) insures properties against flooding losses in the Bay Area through the National Flood Insurance Program. Those properties that have had more than one insured flood loss are called "repetitive loss properties." There are 1,417 properties that have experienced repetitive losses in the Bay Area, resulting in a total of 4,269 claims totaling $98,159,564, of which $65,454,919 was in Sonoma County. Almost all of these losses occurred in the unincorporated portion of that county. See *Table 13: Repetitive Flood Losses* for data on the impacted cities.

TABLE 13 – Repetitive Loss Summary

Data as of 3/31/09

City and County	Total Payments ($)	Average Payment ($)	Losses	Properties	Properties (as of 2004)
Alameda County					
Alameda County (unincorporated)	70,136.24	17,534.06	4	2	1
Alameda	-	-	-	-	-
Albany	-	-	-	-	-
Berkeley	-	-	-	-	-
Dublin	-	-	-	-	-
Emeryville	-	-	-	-	-
Fremont	-	-	-	-	-
Hayward	25,797.84	12,898.92	2	1	1
Livermore	-	-	-	-	-
Newark	-	-	-	-	-
Oakland	50,540.72	4,211.73	12	6	5
Piedmont	10,015.62	5,007.81	2	1	1
Pleasanton	17,639.42	8,819.71	2	1	1
San Leandro	-	-	-	-	-
Union City	385,555.39	192,777.70	2	1	1
Contra Costa County					
Contra Costa County (unincorporated)	348,428.46	15,149.06	23	10	8
Antioch	1,022,300.38	35,251.74	29	10	5
Brentwood	-	-	-	-	-
Clayton	-	-	-	-	-
Concord	67,154.16	8,394.27	8	3	2
Danville	-	-	-	-	-
El Cerrito	17,994.04	4,498.51	4	2	2
Hercules	-	-	-	-	-
Lafayette	50,613.36	12,653.34	4	2	2
Martinez	365,453.52	13,535.32	27	13	7
Moraga	-	-	-	-	-
Oakley	5,134.79	1,711.60	3	1	0
Orinda	155,106.69	19,388.34	8	2	2
Pinole	-	-	-	-	-
Pittsburg	8,606.62	4,303.31	2	1	0
Pleasant Hill	180,282.96	22,535.37	8	4	2

TABLE 13 – Repetitive Loss Summary (cont.)

Richmond	127,146.46	9,780.50	13	6	6
San Pablo	252,198.88	16,813.26	15	6	5
San Ramon	-	-	-	-	-
Walnut Creek	499,979.81	26,314.73	19	7	5
Marin County					
Marin County (unincorporated)	3,922,078.96	17,052.52	230	86	55
Belvedere	71,271.84	17,817.96	4	2	1
Corte Madera	470,210.34	31,347.36	15	7	4
Fairfax	464,153.24	22,102.54	21	6	3
Larkspur	295,608.01	14,780.40	20	6	4
Mill Valley	404,816.78	13,058.61	31	11	8
Novato	1,204,606.78	12,291.91	98	37	29
Ross	1,582,514.94	37,678.93	42	13	4
San Anselmo	97,285.14	13,897.88	7	3	3
San Rafael	1,746,590.19	17,642.33	99	33	31
Sausalito	205,535.01	13,702.33	15	5	4
Tiburon	47,255.39	7,875.90	6	3	3
Napa County					
Napa County (unincorporated)	3,651,710.92	27,875.66	131	43	31
American Canyon	-	-	-	-	-
Calistoga	-	-	-	-	-
Napa	6,982,483.92	33,092.34	211	72	58
St. Helena	446,665.75	44,666.58	10	4	4
Yountville	104,240.33	11,582.26	9	3	2
City and County of San Francisco					
San Francisco City and County	109,663.73	9,969.43	11	4	4
San Mateo County					
San Mateo County (unincorporated)	103,179.64	11,464.40	9	4	2
Atherton	-	-	-	-	-
Belmont	26,990.11	6,747.53	4	2	2
Brisbane	-	-	-	-	-
Burlingame	25,829.85	6,457.46	4	2	2
Colma	-	-	-	-	-
Daly City	109,883.62	13,735.45	8	3	3
East Palo Alto	-	-	-	-	-
Foster City	-	-	-	-	-
Half Moon Bay	-	-	-	-	-
Hillsborough	-	-	-	-	-
Menlo Park	12,141.66	6,070.83	2	1	0
Millbrae	123,354.54	8,223.64	15	5	3
Pacifica	96,812.63	19,362.53	5	2	2
Portola Valley	522,164.53	130,541.13	4	2	1
Redwood City	73,033.16	18,258.29	4	2	2
San Bruno	48,118.22	16,039.41	3	1	1
San Carlos	28,081.97	7,020.49	4	2	1
San Mateo	22,906.57	5,726.64	4	2	0

TABLE 13 – Repetitive Loss Summary (cont.)

South San Francisco	815,490.80	54,366.05	15	5	4
Woodside	-	-	-	-	-
Santa Clara County					
Santa Clara County (unincorporated)	341,585.74	12,651.32	27	10	8
Campbell	-	-	-	-	-
Cupertino	49,259.62	24,629.81	2	1	1
Gilroy	-	-	-	-	-
Los Altos	-	-	-	-	-
Los Altos Hills	-	-	-	-	-
Los Gatos	5,393.99	2,697.00	2	1	1
Milpitas	-	-	-	-	-
Monte Sereno	-	-	-	-	-
Morgan Hill	106,064.04	11,784.89	9	4	3
Mountain View	-	-	-	-	-
Palo Alto	692,067.82	40,709.87	17	5	6
San Jose	154,455.70	8,129.25	19	7	7
Santa Clara	-	-	-	-	-
Saratoga	-	-	-	-	-
Sunnyvale	30,730.37	15,365.19	2	1	0
Solano County					
Solano County (unincorporated)	1,790,593.63	40,695.31	44	17	6
Benicia	-	-	-	-	-
Dixon	10,487.54	5,243.77	2	1	0
Fairfield	417,634.31	41,763.43	10	4	0
Rio Vista	464,008.39	58,001.05	8	3	3
Suisun City	349,740.27	21,858.77	16	4	3
Vacaville	589,867.88	42,133.42	14	6	0
Vallejo	227,990.96	8,142.53	28	12	11
Sonoma County					
Sonoma County (unincorporated)	60,354,563.70	22,613.17	2669	830	719
Cloverdale	-	-	-	-	-
Cotati	-	-	-	-	-
Healdsburg	398,506.82	13,283.56	30	10	8
Petaluma	3,250,630.77	33,169.70	98	34	32
Rohnert Park	-	-	-	-	-
Santa Rosa	234,392.07	14,649.50	16	5	2
Sebastopol	1,090,447.52	49,565.80	22	10	8
Sonoma	126,378.43	21,063.07	6	2	3
Windsor	-	-	-	-	-
Total	**98,159,563.50**	**22,993.57**	**4,269**	**1,417**	**1,148**

The use of this information is limited because the data are not geo-located. Thus, no map of these properties can be produced and no assessment of the location of these properties versus either Q3 or D-FIRM flood hazard maps can be generated. However, using older data, ABAG examined these properties relative to the Q3 maps. As shown in ***Table 13***, below, a total of 921 of the properties are located in the 100-year flood plain. An additional 80 are located in the areas mapped as a 500-year flood zone or area of other concern. The remaining 157 properties are located outside of these mapped hazard areas.

See http://quake.abag.ca.gov/mitigation/floodloss.html for more information for individual counties and cities on the repetitive flood losses versus Q3 flood mapping.

TABLE 14 – 2005 Repetitive Flood Losses versus Q3 FIRMS

	Total Number of Properties	Within 100-Year Flood Zone	Within 500-Year Flood Zone or Other Area of Concern	Not Within the Mapped Flood Zone	Number of Claims
Total	1,158	921	80	157	3,218
Alameda	10	2	0	8	20
Contra Costa	46	29	9	8	103
Marin	149	124	6	19	398
Napa	95	67	7	21	247
San Francisco	4	0	0	4	11
San Mateo	23	8	4	11	56
Santa Clara	27	19	4	4	67
Solano	28	22	5	1	76
Sonoma	776	650	45	81	2,240

Past flood losses as an indicator of future vulnerability

Past flooding losses have been significant, but not as large as for earthquakes. For example, the January 1997 floods resulted in $1.8 billion in total damage in California, while the El Nino storms of early 1998 resulted in $550 million in losses in the entire state, including both flooding and landslides impacts. FEMA documents over $98 million in total repetitive losses in the Bay Area that have been paid by their insurance program since its inception, most of which (over $65 million) has occurred in Sonoma County. The Holland and Webb Tracts levee breaks in 1980 impacted Contra Costa, Sacramento, and San Joaquin counties and resulted in $17.4 million in damage. However, since **6.4%** of the urban land in the Bay Area is within the 100-year flood plain, and climate change may increase the size of spring runoff, future losses could be more significant than in the past. Note that some of the repetitive loss claims have occurred in areas outside of the Q3-mapped 100-year flood plain. Thus, it is clear that other areas are susceptible to flooding, but to a lesser extent.

Landsliding

Landsliding probabilities, location, and extent

Winter rain storms also impact our hillsides by triggering debris flows and more slow-moving traditional landslides. The U.S. Geological Survey has developed maps depicting both ***debris flow*** source areas (***Plate 45***) and ***existing landslides*** (***Plate 46***). The map of existing landslides covers areas of severe coastal erosion.

No formal estimates of probability are associated with these maps and there is no way to estimate these probabilities within the scope of this Local Hazard Mitigation Plan. In general, landslides are most likely during periods of higher than average rainfall or El Nino winter storms. In addition, the ground must be saturated prior to the onset of a major storm for significant landsliding to occur. But there is also no way to estimate the scale of individual landslides in terms of size or extent based on these maps, or to assign specific probabilities to these areas in terms of the likelihood of future landslides. In general, USGS continues to devote fewer resources to landslide mapping (and no resources to probability modeling) than to earthquake hazard mapping because landslides tend to have much more isolated impacts. Thus, qualitatively, the probability of a specific mapped area experiencing a slide in a given year is low and typically localized. On the other hand, there are some known areas of higher than average problems including Devil's Slide on the San Mateo County coast, Mission Peak landslide above Fremont, the Oakland-Berkeley Hills, and the hills of Marin County. None of ABAG's applications for funding of landslide hazard risk assessments have been funded, and the efforts of the California Geological Survey have been underfunded.

TABLE 15 – SUPPLEMENTARY INFORMATION FOR PLATE 46: Summary Distribution of Slides and Earth Flows in the San Francisco Bay Region

Susceptibility Value on Map	**"Official" Full Description** (from USGS Open File Report 97-745E, 1997)
Mostly Landslides	**Mostly Landslides** - consists of mapped landslides, intervening areas typically narrower than 1500 feet, and narrow borders around landslides; defined by drawing envelopes around groups of mapped landslides.
Many Landslides	**Many Landslides** - consists of mapped landslides and more extensive intervening areas than in 'Mostly Landslide'; defined by excluding areas free of mapped landslides; outer boundaries are quadrangle and county limits to the areas in which this unit was defined.
Flatland	**Flat Land** - areas of gentle slope at low elevation that have little or no potential for the formation of slumps, translational slides, or earth flow except along stream banks and terrace margins; defined by the distribution of surficial deposits.
Few Landslides	**Few Landslides** - contains few, if any, large mapped landslides, but locally contains scattered small landslides and questionably identified larger landslides; defined in most of the region by excluding groups of mapped landslides but defined directly in areas containing the 'Many Landslides' unit by drawing envelopes around areas free of mapped landslides.
Very Few Landslides	**Very Few Landslides** – (no additional information provided)

The list of mitigation strategies includes several relating to ways in which local governments can increase the speed of completion of hazard maps, particularly GOVT-d-10 and LAND-a-7. The local governments in the Bay Area continue to support efforts by CGS and USGS to collect data and obtain funding for additional studies related to rainfall-induced landslide hazards in the Bay Area. More detailed maps for individual local governments and additional landslide hazard information are available on line at http://quake.abag.ca.gov/landslide.

Past occurrences of Bay Area landslide-related disasters

Flooding and landsliding associated with severe storms have been among the most common disasters in the Bay Area during the period from 1950 to 2009.

Extensive Landslides occurred in 1950, 1955, 1957, 1958, 1959,1962, 1963, 1964, 1965, 1966, 1969, 1970, 1973, 1980, 1982, 1983, 1992, 1995, 1996, 1997, 1998, 2005, 2006, and 2008.

See Appendix D and http://quake.abag.ca.gov/mitigation/disaster-history.html for more specific information.

Exposure and vulnerability of the Bay Area to landslide-related disasters

One method of assessing vulnerability is to examine existing land uses in mapped hazard areas.

Existing landslide areas and existing land use

- Of the 4.39 million acres of land in the Bay Area, 23.1% are in areas mapped as mostly landslides on the existing landslide map.
- Only 8.3% of the urban land is in these mostly landslide areas, versus 28.2% of the non-urban land. Thus, in general, we are avoiding these areas.
- Types of existing urban land uses with the highest percentages in these mostly landslide areas are urban open space (14.4%) and residential use (9.9%).
- Of the 94,704 acres of urban land in these areas of extensive landslides, 58.1% is residential use.
- The percentage of urban land located in these mostly landslide areas ranged from a highs of 17.7% in Marin County, 13.7% in Sonoma County, and 10.9% in Contra Costa County to a low of 1% in San Francisco.

These percentages are based on information in ***Table 15:*** *Existing Landslide Areas and Existing Land Use*. See ***Plate 46*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Existing landslide areas and existing infrastructure

- While 3.9% of the miles of pipelines and 7.2% of the miles of roads are in areas mapped as mostly landslides, only 2.1% of the miles of transit miles and 1.6% of the rail miles are in these areas. None of the MUNI or VTA light rail lines are located in these areas, and only 1.6% of rail, 7.3% of ACE, 1.7% of Amtrak, 4% of BART, and 1.3% of Caltrain lines are in these areas.

TABLE 16 – Landslide Hazard and Existing (2005) Land Use

	Total Acres	In Areas of Mostly Landslides	% of Land in Areas of Mostly Landslides
Total	4,387,602	1,011,780	23.1%
Urban	1,139,000	94,704	8.3%
Non-Urban	3,248,602	917,077	28.2%
URBAN ONLY:			
Residential	555,463	54,994	9.9%
Mixed R+C	1,775	7	0.4%
Commercial/ Services	110,502	4,020	3.6%
Mixed C+I	3,344	88	2.6%
Industrial	72,125	2,874	4.0%
Military	30,549	667	2.2%
Infrastructure	205,807	9,046	4.4%
Urban Open	159,435	23,008	14.4%
URBAN ONLY:			
Alameda	180,056	9,462	5.3%
Contra Costa	184,775	20,060	10.9%
Marin	54,146	9,588	17.7%
Napa	35,727	2,063	5.8%
San Francisco	29,273	286	1.0%
San Mateo	104,530	8,752	8.4%
Santa Clara	221,865	9,915	4.5%
Solano	100,720	3,360	3.3%
Sonoma	227,908	31,218	13.7%
	Total Miles	In Areas of Mostly Landslides	% of Miles in Areas of Mostly Landslides
INFRASTRUCTURE:			
Roads	33,021	2,390	7.2%
Transit	433	9	2.1%
Rail	940	15	1.6%
Pipelines	21,851	848	3.9%
	Total Number	In Areas of Mostly Landslides	% in Areas of Mostly Landslides
CRITICAL FACILITIES:			
Health Care	840	7	0.8%
Schools	2,805	45	1.6%
Bridges	4,153	195	4.7%
Water Facilities	2,095	231	11.0%
Wastewater Facilities	338	2	0.6%
Cities & Counties	4,195	110	2.6%

See http://quake.abag.ca.gov/mitigation/pickdbh2.html and http://quake.abag.ca.gov/pickcrit2010.html for more specific information.

- The exposure of pipelines and roads to landslide hazards is greatest in Marin County, where 15.7% of the pipelines and 18.3% of the roads are in these areas of existing landslides.

These percentages are based on information in ***Table 16:*** *Existing Landslide Areas and Existing Land Use*. See ***Plate 46*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Existing landslide areas and existing critical facilities

- Of the 840 critical health care facilities in the Bay Area, only 0.8% are in areas mapped as mostly landslides on the existing landslide map.
- Of the 2,805 public schools in the Bay Area, only 1.6% are in areas mapped as mostly landslides on the existing landslide map.
- Of the 6,153 critical facilities owned by cities, counties, and other special districts in the Bay Area, 5.2% are in areas mapped as mostly landslides on the existing landslide map.

These percentages are based on information in ***Table 15:*** *Existing Landslide Areas and Existing Land Use*. See ***Plate 46*** and http://quake.abag.ca.gov/mitigation/pickcrit2010.html, for more specific information for individual counties and cities.

Past landslide losses as an indicator of future vulnerability

Losses from landslides are typically lower than associated flooding. However, in the El Nino storms of early 1998, USGS documented approximately $150 million in losses due to approximately 300 landslides that occurred in the Bay Area and Santa Cruz County[12]. The landslides ranged in size from a 25 m^3 failure of engineered material to a reactivation of the massive (13 million m^3) Mission Peak earthflow complex in Alameda County.

[12] Godt, J.W. , ed., 1999. "Introduction" in ***Maps Showing Locations of Damaging Landslides Caused by El Nino Rainstorms, Winter Season1997-98, San Francisco Bay Region, California***: U.S. Geological Survey Misc. Field Studies Map MF 2325-A-J: Reston, VA. See http://pubs.usgs.gov/mf/1999/mf-2325/.

Wildfire

Wildfire probabilities, location, and extent

Just as weather can result in too much water, the Bay Area's weather can result in too little water. One of the resulting hazards is ***wildfire***. CalFIRE has developed several maps depicting wildfire hazard areas. The two most useful maps are those depicting Wildland Urban Interface (WUI) wildfire threat (***Plate 47***) and wildfire threat from wildland fuels in State Responsibility Areas (***Plate 48***). The WUI map depicts communities within 1.5 miles of a potential wildfire source, as determined by CDF-FRAP fuel and hazard data. Additional maps include a map of perimeters of past large fires (300 acre minimum for CDF fires since 1950 and 10 acre minimum for USFS fires since 1878 (***Plate 49***), a map of fire-related risks to ecosystem health as measured by condition class (***Plate 50***), a map of the distribution of wildland-urban-interface housing unit density (***Plate 51***), and a map of post-fire risk of increased surface erosion (***Plate 52***). More detailed maps for individual local governments and additional wildfire hazard information are available on line at http://quake.abag.ca.gov/wildfire.

Using a combination of the map of past wildfires (***Plate 49***) in combination with the fire threat maps (***Plates 47 and 48***), a table of the probability of an area burning in the next 130 years could be calculated. Based on an analysis of data on wildfires during the past 130 years, only 0.24% of the areas mapped as an extreme wildfire threat have burned, 22.8% of those mapped as very high, and 18.5% of those mapped as high. In addition, 4.5% of the areas in wildland-urban-interface fire threat areas have burned.[13] Thus, the probability of the areas mapped as very high hazard on the wildfire threat has traditionally been much greater than those mapped on the wildland-urban-interface fire threat map. On the other hand, the wildland-urban-interface fire threat map shows more urban areas with a greater potential property value and high fuel loads. In addition, the number of fires, and the size of those fires, has been increasing over time. More specific results of this analysis are shown in ***Table 17***, below.

TABLE 17 – Estimate of Probability of Fire Affecting a Given Area Based on Data from Past 50 Years

Threat Category	Acres Burned from 1878 through 2008	Total Number of Acres Within Threat Classification	Percent of Acres That Burned in Past 130-Year Period
On Wildfire Threat Map			
Moderate	41,651	1,300,662	3.20%
High	218,947	1,183,899	18.49%
Very High	306,264	1,344,664	22.78%
Extreme	5	2,272	0.24%
On Wildland Urban Interface Fire Threat Map			
WUI Acres	37,037	819,317	4.52%

[13] Source – Data from analysis of California Department of Forestry maps at http://www.abag.ca.gov/bayarea/eqmaps/wildfire/. (Also see Table 5.)

TABLE 18 – SUPPLEMENTARY INFORMATION FOR PLATES 47 and 48: Wildland-Urban-Interface (WUI) Fire Threatened Communities and Fire Threat in the San Francisco Bay Region Map

Using a combination of the map of past wildfires (***Plate 49***) in combination with the fire threat maps (***Plates 47 and 48***), a table of the probability of an area burning in the next 50 years can be calculated. The results are shown in the following table and in ***Table 7*** of Appendix C.

Susceptibility Value on Map	Acres Burned in Past 50 Years	Total Number of Acres Within Threat Classification	Percent of Acres That Burned in Past 50-Year Period
ON WUI MAP			
WUI Community at Risk	37,037	819,317	4.52%
ON FIRE THREAT MAP			
Extreme Fire Threat	5	2,272	0.24%
Very High Fire Threat	306,264	1,344,664	22.78%
High Fire Threat	218,947	1,183,899	18.49%
Moderate Fire Threat	41,651	1,300,662	3.20%

TABLE 19 – SUPPLEMENTARY INFORMATION FOR PLATE 51: Fire-Related Risks to Ecosystem Health as Measured by Condition Class

	Low Condition Class 1	**Moderate Condition Class 2**	**High Condition Class 3**
Departure From Natural Regimes	None, minimal	Moderate	High
Vegetation Composition, Structure, Fuels	Similar	Moderately altered	Significantly different
Fire Behavior, Severity, Pattern	Similar	Uncharacteristic	Highly uncharacteristic
Disturbance Agents, Native Species, Hydrologic Functions	Within natural range of variation	Outside historical range of variation	Substantially outside historical range of variation
Increased Smoke Production	Low	Moderate	High

SUPPLEMENTARY INFORMATION FOR PLATE 52: Post-Wildfire Soil Erosion Potential

The State of California Multi-Hazard Mitigation Plan references this map. This State Plan provides the following as explanatory material.

> The effects of fire on soil resources are dependent on the intensity of the fire and are induced by soil heating and by removal of the protective cover of vegetation, litter, and duff. The magnitude of soil heating depends on fuel loading, fuel moisture content, fuel distribution, rate of combustion, soil texture, soil moisture content, and other factors. The movement of heat into the soil depends upon the peak temperature of the fire and how long the heat is present. Because fuels are not evenly distributed around a site, a single fire will cause varying levels of soil heating. The highest soil temperatures occur where fuel consumption is greatest and where the duration of burning is longest. Fires in forested areas often cause high soil temperatures due to heavy fuel accumulation. In contrast, rangelands fires are often shorter in duration and cause less soil heating because of their comparatively light fuel load.
>
> FRAP [Fire and Resource Assessment of the California Department of Forestry] used a modified form of the universal soil loss equation to predict potential soil loss from fire across California. The model characterizes the influence of vegetation and other environmental factors on soil erosion using inputs such as soil and precipitation data, topography, and vegetation cover. The main determining factor in predicting potential soil loss is changes to vegetation cover resulting from fire. These changes approximate the increase in surface erosion from future wildfire burning under both current fuel conditions and severe fire weather.

Past occurrences of Bay Area wildfire-related disasters

Wildfires were common disasters in the Bay Area during the period from 1950 to 2009. Large wildfires occurred in 1961, 1962, 1964, 1965, 1970, 1981, 1985, 1988, 1991, and 2008. The largest urban-wildland fire in the Bay Area, the 1991 fire in the East Bay Hills, resulted in $1.7 billion in losses. In that fire, 3,354 family dwellings and 456 apartments were destroyed, while 25 people were killed and 150 people were injured.

See Appendix D and http://quake.abag.ca.gov/mitigation/disaster-history.html for more specific information.

Exposure and vulnerability of the Bay Area to wildfire-related disasters

Based on an examination of the Wildfire-Urban-Interface fire threat map, it is likely that it is radically overestimating the risk to communities on saturated ground near the Bay such as Foster City and the City of Alameda. In 2005, CalFIRE indicated that the maps would be updated to correct this problem. As of December 2009, this change has still not occurred.

One method of assessing vulnerability is to examine existing land uses in mapped hazard areas.

Wildfire and exposure of existing land use

- Of the 4.39 million acres of land in the Bay Area, 18.5% is in Wildland Urban Interface (WUI) wildfire threat areas, while 57.1% is in the high, very high, or extreme wildfire threat areas in State Responsibility Areas (SRAs).

TABLE 20 – Wildfire Hazard and Existing (2005) Land Use

	Total Acres	Wildland Urban Interface Wildfire Threat	High, Very High, or Extreme Wildfire Threat Areas	% of Land in Wildland Urban Interface Wildfire Threat Area	% of Land in High, Very High, or Extreme Wildfire Threat Area
Total	4,387,602	811,634	2,503,779	18.5%	57.1%
Urban	1,139,000	552,159	234,010	48.5%	20.5%
Non-Urban	3,248,602	259,475	2,269,769	8.0%	69.9%
URBAN ONLY:					
Residential	555,463	323,838	127,576	58.3%	23.0%
Mixed R+C	1,775	888	29	50.0%	1.6%
Commercial/ Services	110,502	44,011	11,040	39.8%	10.0%
Mixed C+I	3,344	993	223	29.7%	6.7%
Industrial	72,125	20,544	8,927	28.5%	12.4%
Military	30,549	7,280	7,374	23.8%	24.1%
Infrastructure	205,807	89,016	21,969	43.3%	10.7%
Urban Open	159,435	65,590	56,867	41.1%	35.7%
URBAN ONLY:					
Alameda	180,056	77,727	21,963	43.2%	12.2%
Contra Costa	184,775	118,828	32,108	64.3%	17.4%
Marin	54,146	40,256	12,469	74.3%	23.0%
Napa	35,727	15,564	11,154	43.6%	31.2%
San Francisco	29,273	13,780	656	47.1%	2.2%
San Mateo	104,530	55,980	17,000	53.6%	16.3%
Santa Clara	221,865	91,768	22,194	41.4%	10.0%
Solano	100,720	33,239	14,283	33.0%	14.2%
Sonoma	227,908	105,017	102,181	46.1%	44.8%
	Total Miles	Wildland Urban Interface Wildfire Threat	High, Very High, or Extreme Wildfire Threat Areas	% of Miles in Wildland Urban Interface Wildfire Threat Area	% of Miles in High, Very High, or Extreme Wildfire Threat Area
INFRASTRUCTURE:					
Roads	33,021	14,798	5,407	44.8%	16.4%
Transit	433	123	24	28.4%	5.5%
Rail	940	264	82	28.1%	8.7%
Pipelines	21,851	11,172	1,301	51.1%	6.0%
	Total Number	Wildland Urban Interface Wildfire Threat	High, Very High, or Extreme Wildfire Threat Areas	% in Wildland Urban Interface Wildfire Threat Area	% in High, Very High, or Extreme Wildfire Threat Area
CRITICAL FACILITIES:					
Health Care	840	322	5	38.3%	0.6%
Schools	2,805	1,325	70	47.2%	2.5%
Bridges	4,153	1,646	255	39.6%	6.1%
Water Facilities	2,095	1,400	307	66.8%	14.7%
Wastewater Facilities	338	150	5	44.4%	1.5%
Cities & Counties	4,195	1,936	151	46.2%	3.6%

See http://quake.abag.ca.gov/mitigation/pickdbh2.html and http://quake.abag.ca.gov/pickcrit2010.html for more information.

- 48.5% of the urban land is in the WUI wildfire threat areas, versus 8% of the non-urban land. On the other hand, 20.5% of the urban land is in the SRA high, very high, or extreme wildfire threat areas, versus 69.9% of the non-urban land. This discrepancy is to be expected because the State focuses on non-urban areas.
- Types of existing urban land uses with the highest percentages in WUI wildfire threat areas are residential (58.3%), mixed residential-commercial (50%), infrastructure use (43.3%), and urban open (41.1%).
- Of the 552,159 acres of urban land in these WUI wildfire threat areas, 58.6% is residential use.
- The percentage of urban land located in WUI wildfire threat areas ranged from a high of 74.3% in Marin County and 64.3% in Contra Costa County to a low of 33% in Solano County.

These percentages are based on information in ***Table 20:*** *Wildfire Hazards and Existing Land* ***Use***. See ***Plates 47 and 48,*** as well as http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Wildfire and exposure of existing infrastructure

- While 44.8% of the region's roads are in WUI wildfire threat areas, only 28.4% of the transit lines only 28.1% of the rail are in these areas. (25.5% of ACE, 21% of Amtrak, 38.6% of BART, 32.5% of Caltrain, 32.4% of SF MTA (MUNI), and 19% of the VTA lines, are in wildland-urban-interface fire threat areas.)
- While 16.4% of the region's roads are in areas mapped as having high, very high, or extreme wildfire threat, only 5.5% of the transit lines and 8.7% of the rail lines are in these areas.
- 12.7% of ACE, 0.8% of Amtrak, 3% of BART, none of Caltrain, none of SF MTA (MUNI), and none of the VTA lines, are in areas of very high or extreme wildfire threat.
- Data on pipelines, though provided, is not particularly relevant because underground pipelines are not particularly vulnerable to damage from wildfires.

These percentages are based on information in ***Table 20:*** *Wildfire Hazards and Existing Land Use*. See ***Plates 47 and 48***, as well as http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Wildfire and exposure of existing critical facilities

- Of the 840 critical health care facilities in the Bay Area, 38.3% are in WUI wildfire threat areas, while only 0.6% are in areas mapped as having high, very high, or extreme wildfire threat.
- Of the 2,805 public schools in the Bay Area, 47.3% are in WUI wildfire threat areas, while 2.5% are in areas mapped as having high, very high, or extreme wildfire threat.
- Of the 6,153 critical facilities owned by cities, counties, and other special districts in the Bay Area, 52.6% are in WUI wildfire threat areas, while 6.9% are in areas mapped as having high, very high, or extreme wildfire threat.
- These statistics point to the need to ensure that basic fire mitigation measures are undertaken for these exposed facilities.

These percentages are based on information in ***Table 20: Wildfire Hazards and Existing Land Use***. See ***Plates 47 and 48***, as well as http://quake.abag.ca.gov/mitigation/pickcrit2010.html, for more specific information for individual counties and cities.

Past wildfire losses as an indicator of future vulnerability

The largest urban-wildland fire in the Bay Area, the 1991 fire in the East Bay Hills, resulted in $1.7 billion in losses. In that fire, 3,354 family dwellings and 456 apartments were destroyed, while 25 people were killed and 150 people were injured. While in the 2005 MJ-LHMP, it was assumed that it was is unlikely that any single fire disaster in the Bay Area would exceed that fire in total losses, that assumption can no longer be made. A combination of increasing property values in wildfire areas, increasing fuel, and climate change all contribute to this change. However, these losses are many times smaller and more localized than that anticipated from a disastrous earthquake.

Drought

Drought probabilities, location, and extent

What would be a drought in other areas of the country is controlled in the Bay Area through the importation of water and the storage of water in reservoirs. Prolonged periods of drought cause additional drought-related problems, including crop losses and shortages of water for landscaping.

Drought can impact the entire Bay Area, not just one particular county or a few cities. In addition, shortages in precipitation in the Sierra Nevada can have a more pronounced impact on water supply in the region than a drought in the Bay Area itself because of the reliance of the region of water from the Tuolumne and Mokelumne watersheds. Thus, drought is not a hazard that can be depicted in map form.

There is also no current data on the probability of drought that would be comparable to the USGS effort on earthquakes in the region, or the way 100-year flood maps are created. Such an effort has been promoted by the Western Governors' Association as part of a National Integrated Drought Information System in a 2004 report, *Creating a Drought Early Warning System for the 21st Century*. In that report, WGA notes,

> Droughts are as much a part of the weather and climate extremes as floods, hurricanes and tornadoes. Yet in marked contrast to the myriad federal programs that report, prevent and mitigate the damage of these other extreme events, we passively accept drought's effects as an unavoidable natural hardship. This passive approach to droughts is manifested in our lack of a comprehensive federal drought policy: we respond to droughts through ad hoc, crisis management, rather than through proactive, coordinated strategies designed to mitigate the impacts. To address other natural disasters — floods, hurricanes, tornadoes, etc. — Congress enacted the Stafford Act, which gives clear roles and responsibilities to the various federal agencies and makes the Federal Emergency Management Agency (FEMA) the federal lead."

Thus, while long-term drought probabilities are not yet available, annual monitoring has started. See http://www.westgov.org/wga/publicat/nidis.pdf and http://www.drought.unl.edu/dm/monitor.html for more information. Short-term drought prediction is possible based on current and past weather patterns. For example, while California has experienced drought conditions between 2006 and 2009, the 2009-10 winter was exceptionally wet with late season snow fall in the Sierra mountains that filled many reservoirs to capacity due to El Nino conditions. Based on this information, California is not expected to experience drought conditions in 2010-11.

The list of mitigation strategies includes several relating to ways in which local governments can help efforts to increase the knowledge of this hazard and/or plan for its impacts, particularly INFR a-13, GOVT c-23, GOVT-d-10, ENVI-a-3, and ENVI-b-1.

Past occurrences of Bay Area drought-related disasters

Major droughts were in 1973, 1976, and 2009. Climate change is likely to increase the number and severity of future droughts. The magnitude of this change is currently unknown.
See Appendix D and http://quake.abag.ca.gov/mitigation/disaster-history.html for more specific information.

Exposure and vulnerability of the Bay Area to drought-related disasters

All of the 4.39 million acres of land in the Bay Area is subject to drought.

The report on *Hetch-Hetchy Water and the Bay Area Economy* discussed earlier hints at the importance of water to the region and the potential impacts of drought and population growth. That report notes on page 5 that:

> Based on conditions during the most recent drought period, SFPUC now has determined that the maximum quantity of water it can reliably deliver to its customer base is 239 mgd annually. However, actual demand in 2000-2001 was nearly 260 mgd, and it is generally understood that the SFPUC system is operating in excess of its assured supply capacity and approaching its actual delivery capacity.
>
> Total demand for Hetch Hetchy water is expected to grow to 303 mgd in 2030 and 310 mgd by 2050. Absent a significant expansion of the system, the shortfall relative to assured supply will therefore increase from 21 mgd presently to 64 mgd within 30 years and 71mgd within 50 years.

Most Bay Area water districts develop long-term water supply and management plans, including urban water shortage contingency analyses. ABAG will be working with water districts and others on this issue, as specified in the ABAG Annex, Mitigation Strategy INFR-d-4, ENVI-a-4 and ENVI-a-5.

The *Executive Summary* of the *Integrated Regional Water Management Plan for the San Francisco Bay Area* states that "the San Francisco Bay Area water, wastewater, flood protection and stormwater management agencies; cities and counties represented by the Association of Bay Area Governments (ABAG); and watershed management interests represented by the California Coastal Conservancy (CCC) and non-governmental environmental organizations signed a Letter of Mutual Understandings (LOMU) to develop an Integrated Regional Water Management Plan (IRWMP) for the San Francisco Bay Area."

According to that BA-IRWMP,

> … the Bay Area's existing annual supplies are inadequate to meet projected demands during prolonged drought periods. As the population continues to grow - the gap between available supplies and customer demand will widen in the coming decades unless agencies have the resources to fully implement necessary actions. … Historically, conservation measures have proven to be effective at controlling Bay Area water use. Overall water use has only increased 1% since 1986 – despite a 23% increase in population.

Finally, the BA-IRWMP notes, "Many sources of supply for the Bay Area are limited in dry years. If the Bay Area experiences another multi-year drought similar to that of the 1987-1992 drought, the following supply reductions are expected for the region:

- 60% reduction in [State Water Project] SWP supplies
- 25% reduction in [Central Valley Project] CVP supplies
- 30% reduction in Tuolumne supplies [source of SF PUC supply]
- 40% reduction in Mokelumne supplies [source of EBMUD water supply]
- 50% +/- reduction in local supplies"

The IRWMP can be accessed at http://bairwmp.org/plan/bay-area-irwmp-document-1.

Climate Change

Climate change probabilities, location, and extent

Over geologic time, carbon dioxide was sequestered in the earth in the form of coal and fossil fuels. In modern times those resources have been extracted and released into the atmosphere through burning for energy use. Carbon dioxide (CO_2), along with methane (CH_4), nitrous oxide (N_2O), and water vapor, which accumulate in the atmosphere, absorb infrared light and radiate heat back to the earth's surface, leading to overall higher temperatures on earth. This process can have disparate effects in individual locations on earth, with some locations experiences colder temperatures and some experiences warmer temperatures. The effects of climate change are varied: warmer and more varied weather patterns, sea level rise, melting ice caps, and poor air quality, for example.

The impacts of climate change on wildfires, floods, drought, and levee failure hazards are discussed in those individual sections of this Appendix. An additional hazard associated with climate change is sea level rise. While this hazard impacts floods and levee failure hazards, it is also a hazard of its own. This hazard directly impacts those jurisdictions that touch the bay or ocean as homes, businesses, and infrastructure located near the shoreline may become inundated over time by rising sea levels. Historic records show that sea level in the San Francisco Bay has risen by as much as seven inches in the past century[14]. Based on research conducted by scientists at the U.S. Geological Survey, a sea level rise of 16 to 55 inches over the next century will affect the shoreline of the Bay and Delta, and increase the risk of levee failures[15]. The Bay Conservation Development Commission has developed maps depicting the lands most vulnerable to sea level rise[16] (***Plate 54***). This map depicts 16 inches of sea level rise at mid-century and 55 inches at the end of the century, respectively. More detailed maps for individual local governments and additional wildfire hazard information are available online at http://quake.abag.ca.gov/climatechange/

Climate change is one of the few natural hazards where the probability of occurrence is influenced by human action. In addition, unlike earthquake and floods that occur over a finite time period, climate change is an on going hazard of which we are already experiencing some of the effects. Other effects may not be seriously experienced for decades, or may be avoided altogether by mitigation actions taken today.

Scientists have developed forecasts for global warming and climate change that take into account a range of possible responses to climate change. If green house gas emissions were to remain constant at year 2000 levels, it is likely that average global surface temperature would rise between 0.3 and 0.9 degrees Centigrade by the end of the century[17]. Under the most extreme

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[14] California Natural Resources Agency, 2009: *California Climate Adaptation Strategy, A Report to the Governor of the State of California in Response to Executive Order S-13-2008.*

[15] Knowles, N., 2008. "Projecting Inundation Due to Sea Level Rise in the San Francisco Bay and Delta" presented at the Third Annual Climate Change Research Conference, September 2008, Sacramento, California.

[16] *Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on the Shoreline, Draft Report.* April 7, 2009. San Francisco Bay Conservation and Development Commission

[17] IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S.,

scenario of continued increase of green house gas emissions over time, scientists predict that it is likely that average global surface temperature will rise between 2.4 and 6.4 degrees Centigrade.

Past occurrences of Bay Area climate change disasters

Climate change has never been directly responsible for any declared disasters. Past flooding, wildfire, levee failure, and drought disasters may have been exacerbated by climate change, but it is impossible to make direct connections to individual disasters. Sea level rise is an ongoing challenge for the San Francisco Bay, but adaptations strategies are underway to mitigate its effect.

Exposure and vulnerability of the Bay Area to climate change-related disasters

An estimated 270,000 people and $62 billion in economic resources at risk of flooding by the end of the century due to the 55 inch sea level rise scenario[18]. Some critical facilities at risk from sea level rise include the Oakland and San Francisco Airports, and Port of Oakland. Some cities are particularly vulnerable to sea level rise due to their location along the Bay and low elevations. Residential and commercial properties along the entire bay and ocean coastline are at risk, especially marinas, piers, walking and biking trails, and natural habitat.

- Of the 840 critical health care facilities in the Bay Area, 16 are in 55-inch inundation zone, while 10 are in the 16-inch inundation zone.
- Of the 2,805 public schools in the Bay Area, 38 are in 55-inch inundation zone, while 52 are in the 16-inch inundation zone.
- Of the 4,153 bridges in the Bay Area, 134 are in the 16-inch inundation zone. There are no additional bridges in the 55-inch inundation zone.
- Of the 6,153 critical facilities owned by cities, counties, and other special districts in the Bay Area, 228 are in 55-inch inundation zone, while 291 are in the 16-inch inundation zone.

D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[18] Heberger, M., H. Cooley, P. Herrera, and P. Gleick. 2008. The Impacts of Sea Level Rise Along the California Coast. California Climate Change Center. CEC-500-2008-024-F

Dam Failure

Dam failure probabilities, location, and extent

Dams built in the Bay Area over the last 150 years were constructed using then current construction techniques and seismic knowledge of the time, and many without the benefit of government regulation. Dams built to hold the water in reservoirs can be damaged due to a huge storm and associated runoff, an earthquake, slope failures, or a terrorism event. Understanding the impact of a dam failure is critical for two reasons: (1) their catastrophic failure can kill many people and destroy homes and other structures downstream from the facility, and (2) the storage capacity is lost and not recovered until the dam is rebuilt (a lengthy process).

In the 1970's State law required dam owners to develop maps depicting areas that might be inundated by dam failure. The law required that each map be produced only once, without any requirements for updating. Further, the scenario used to create the maps constrained the results to only a worst case situation that does not fit the historical evidence of why dams fail.

The maps were developed using engineering hydrology principals and represent the best estimate of where the water would flow if the dam completely failed with a full reservoir. The inundation pathway is based on completely emptying the reservoir and does not include run-off from storms. Had the maps have been developed more recently, different assumptions and map-making methods would have been used. In addition, dam inundation maps do not indicate the depth of inundation and may represent only an inch of water over some inundation areas. In 1995, ABAG aggregated these maps into a single regional map (***Plate 53***).

Development downstream of dams, and upgrades to older dams have altered the inundation area of a dam, but the law does not require dam owners to update these maps and no new information is available on inundation areas. These maps still provide an estimate of the general location and extent of dam failure inundation areas. More detailed maps for individual local governments and additional dam failure hazard information may be available in the local jurisdiction annexes.

No quantitative probability information exists for the Bay Area dam failure hazard, in part because when a dam in known to have a failure potential, the water level is reduced to allow for partial collapse without loss of water as required by the State Division of Safety of Dams and by safety protocols established by dam owners. For example, the SF PUC is currently operating Calaveras Reservoir at less than 30% of capacity to avoid a catastrophic release of water. Thus, the probability of failure resulting in damage is approaching zero.

Past occurrences of Bay Area dam failures

While dams have failed elsewhere, a dam has never failed in the Bay Area.

Exposure and vulnerability of the Bay Area to dam-failure disasters

As with the tsunami evacuation planning maps, the dam failure maps are evacuation planning maps. However, in this case, it may be useful to provide exposure information as one way of evaluating the benefits of having safe dams. Reducing the vulnerability of the region to dam failure continues to be an extremely high priority of the dam owners, as described in Chapter 1-Infrastructure.

Dam failure inundation areas and exposure of existing land use

- Of the 4.39 million acres of land in the Bay Area, 10.8% are in areas mapped as dam failure inundation areas.
- 18.1% of the urban land is in these dam failure inundation areas, versus only 8.2% of the non-urban land.
- Types of existing urban land uses with the highest percentages in these dam failure inundation areas are mixed commercial-industrial complexes (31.3%) and industrial use (30.1%).
- Of the 206,593 acres of urban land in these dam failure inundation areas, 38.1% is residential use.
- The percentage of urban land located in these dam failure inundation areas ranged from a high of approximately 32% in Alameda and Santa Clara counties to lows of 4.6% in Marin County and 6.1% in San Francisco.

These percentages are based on information in ***Table 20: Dam Failure Inundation Areas and Existing Land Use***. See ***Plate 53*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Dam failure inundation areas and exposure of existing infrastructure

- 32.2% of the miles of rail and 40.4% of transit lines in the region are in areas mapped as dam failure inundation areas.
- 63.6% of ACE, 45.4% of Amtrak, 17.8% of BART, 51.9% of Caltrain, 8.1% of SF MTA (MUNI), and 59.5% of the VTA lines are in these areas.
- On the other hand, 19.4% of the roads and 20.8% of the pipelines are in these areas.

These percentages are based on information in ***Table 20: Dam Failure Inundation Areas and Existing Land Use***. See ***Plate 53*** and http://quake.abag.ca.gov/mitigation/pickdbh2.html for more specific information for individual counties and cities.

Dam failure inundation areas and exposure of existing critical facilities

- Of the 840 critical health care facilities in the Bay Area, 25.2% are in areas mapped as dam failure inundation areas.
- Of the 2,0805 public schools in the Bay Area, 20.9% are in areas mapped as dam failure inundation areas.
- Of the 6,153 critical facilities owned by cities, counties, and other special districts in the Bay Area, 23% are in areas mapped as dam failure inundation areas.

These percentages are based on information in ***Table 20:*** *Dam Failure Inundation Areas and Existing Land Use*. See ***Plate 53*** and http://quake.abag.ca.gov/mitigation/pickcrit2010.html, for more specific information for individual counties and cities.

These high exposures point to the need to ensure the safety of dams in the region. Existing state and federal laws and requirements should be followed.

Dam owners and operators, under the regulation of the State Division of Safety of Dams, routinely inspect their facilities and reevaluate their safety in light of current engineering and seismology. Based on these assessments, EBMUD is retrofitting San Pablo Dam and Reservoir at a cost of $75 million dollars. The San Francisco PUC Calaveras Dam Replacement Project has an estimated total cost of $409 million dollars.

The potential direct property losses from catastrophic failure of these dams are enormous. The 2005 value of the property improvements in the San Pablo Dam inundation area alone is $1.9 billion. The 2005 value of the property improvements in the Calaveras Reservoir inundation area is $15.6 billion. In one respect, this loss underestimates the potential loss. Since a dam is most likely to fail as a result of ground shaking from a catastrophic earthquake, the combined impact of the two events, as noted in the section on infrastructure interdependencies, will be greater than the individual impact of either disaster on its own. On the other hand, the losses will be minimal when the inundation depth is small (keeping in mind that, due to velocity, losses will exceed that of a "typical" flood to the same depth). However, due to the age of these maps, no reliable inundation depth information is available and thus this analysis could not be completed in a quantitative manner.

TABLE 21 – Dam Failure Inundation Areas and Existing (2005) Land Use

	Total Acres	In Dam Inundation Area	% of Land in Dam Inundation Area
Total	4,387,602	474,350	10.8%
Urban	1,139,000	206,593	18.1%
Non-Urban	3,248,602	267,757	8.2%
URBAN ONLY:			
Residential	555,463	78,652	14.2%
Mixed R+C	1,775	206	11.6%
Commercial/ Services	110,502	27,842	25.2%
Mixed C+I	3,344	1,046	31.3%
Industrial	72,125	21,726	30.1%
Military	30,549	1,521	5.0%
Infrastructure	205,807	45,177	22.0%
Urban Open	159,435	30,422	19.1%
URBAN ONLY:			
Alameda	180,056	56,653	31.5%
Contra Costa	184,775	18,232	9.9%
Marin	54,146	2,516	4.6%
Napa	35,727	7,549	21.1%
San Francisco	29,273	1,773	6.1%
San Mateo	104,530	9,600	9.2%
Santa Clara	221,865	70,317	31.7%
Solano	100,720	16,840	16.7%
Sonoma	227,908	23,113	10.1%
	Total Miles	In Dam Inundation Area	% of Miles in Dam Inundation Area
INFRASTRUCTURE:			
Roads	33,021	6,422	19.4%
Transit	433	175	40.4%
Rail	940	303	32.2%
Pipelines	21,851	4,556	20.8%
	Total Number	In Dam Inundation Area	% in Dam Inundation Area
CRITICAL FACILITIES:			
Health Care	840	212	25.2%
Schools	2,805	586	20.9%
Bridges	4,153	1,187	28.6%
Water Facilities	2,095	425	20.3%
Wastewater Facilities	338	103	30.5%
Cities & Counties	4,195	996	23.7%

See http://quake.abag.ca.gov/mitigation/pickdbh2.html and http://quake.abag.ca.gov/pickcrit2010.html for more specific information.

Delta Levee Failure

Delta levee failure probabilities, location, and extent

The probability of levee failure is increasing over time due to sea level rise, increased flooding potential due to early winter snow melts, and earthquake probabilities. Some researchers have estimated the likelihood of a multiple levee failure disaster at about 2% per year.

The Delta Risk Management Study (DRMS)[19] performed a time-dependent Probabilistic Seismic Hazard Analysis (PSHA) that identified likely ground motions at six different locations (shown on Figure 1) around the Delta and their likely recurrence rate at selected times over the next 200 years. The study evaluated all faults that could impact the Delta including major Bay Area faults, seismic sources in the Delta Region (Southern Midland and Western Tracy faults, Northern Midland, Thorton Arch, Montezuma Hills, Tracy and Vernalis zones) and, Coastal Ranges-Sierran Block (CRSB) boundary source zone, Cascadia subduction source zone, and background seismicity.

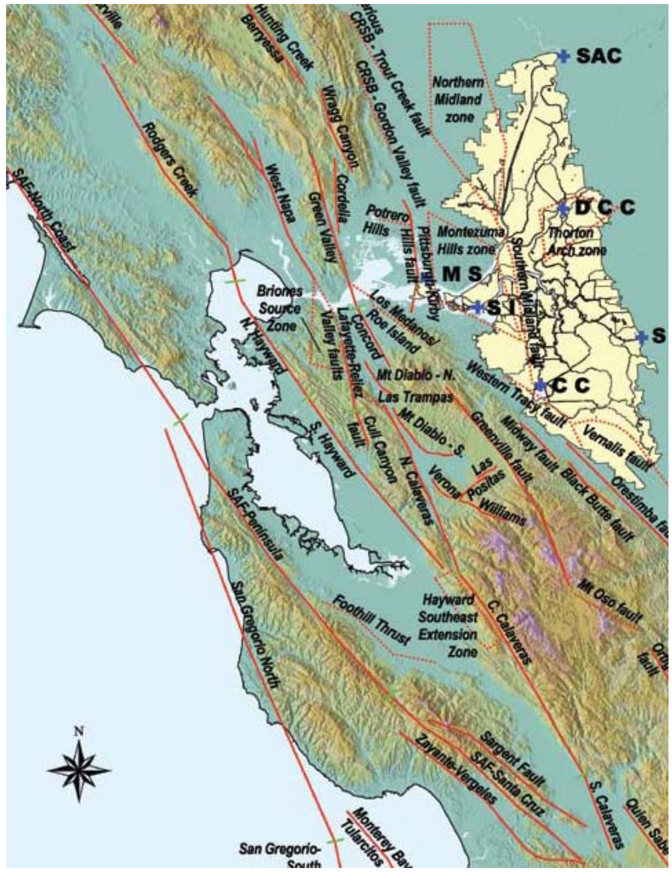

Figure 1: Faults and Seismic Sources in the Delta Region (DRMS 2009, Figure 6-1)

While Bay Area faults, including San Andreas, Hayward, Greenville and Calaveras faults, are well characterized, little is known about the local faults in the Delta. These have only exhibited a low-level pattern of scattered small earthquakes since 1966, but are still believed to be capable of moderate to strong earthquakes (M>6.0). There is no record of M>5.0 earthquakes on Delta faults, but based on geologic formations likely caused by earthquakes and subsurface seismic data, it is believed that earthquakes on these faults occur every couple thousand years.

Similarly, seismic activity is inferred in the CRSB boundary source zone and it is believed that a magnitude 6.5 earthquake is still possible in this zone.

Much of the land in the Delta Region is below sea level and is protected by approximately 1,115 miles of levees in the Delta and 230 miles of levees in the Suisun Marsh. The majority of these levees started out 3 to 5 feet high and were constructed and maintained by local landowners in

[19] Delta Risk Management Strategy, Phase 1, Department of Water Resources, 2009.

the last 130 years to protect farm land from flooding inundation. As a result of land subsidence, sea level rise and increased demand for land in the delta, these levees have been raised and increased in length over the years. Today most of these levees retain water 365 days a year, and carry additional loads during flood events.

An earthquake is the single biggest risk the Delta Region faces. If an earthquake occurs, levees may fail and as many as 20 or more islands may be flooded instantaneously. This would result in an economic impact of $15 billion or more.

Risk reduction strategies to prevent catastrophic failure were not explored in DRMS Phase 1, but they will be the focus of Phase 2 of the study.

The Delta has become integral to our economic and environmental sustainability. In 2005, Assembly Bill 1200 required the Department of Water Resources (DWR) to evaluate the potential impact on Delta water supplies from a variety of hazards. Phase 1 of the Delta Risk Management Strategy (DRMS) was completed in 2008 in response to AB 1200 with the objective of determining whether current business-as-usual management and regulatory practices can sustain the Delta Region for the next 100 years.

DRMS focused on evaluating the hazards of subsidence, earthquakes, floods, changes in precipitation, temperature and ocean levels, and a combination of these hazards.

Identifying the Seismic Hazard

The results of the PSHA indicate that local Delta faults contribute most significantly to the hazard at longer return periods, and will produce stronger shaking due to their proximity to the levees. The major Bay Area faults, however, pose a greater risk to the Delta levees. While they are farther away and will produce smaller ground motions at Delta sites, earthquakes occur much more frequently on these faults. The Hayward fault in particular is the greatest concern for the Bay Area because it is capable of producing large earthquakes which will be devastating to the Bay Area and is close enough to the Delta to damage levees as well. Other Bay Area faults such as the Concord and Green Valley are also likely to produce earthquakes that will damage Delta levees, but these earthquakes will not have the same effect on the Bay Area as a Hayward fault earthquake. Shaking will be strongest in the western delta and decrease to the east due to increasing distance from the Bay Area faults.

While the ground shaking in the delta will be relatively small from a Hayward fault event, the soils in the western delta are extremely weak and liquefaction will trigger at even low levels of shaking (personal communication, Chuck Real, July 29, 2009). This section of the delta is saturated by water nearly to the surface and is composed of very loose sands down to about 70 feet below ground surface. Because the peat that overlays the sand is extremely light, these sands have never been compressed under the weight of the soils above them. These conditions make the soil extremely susceptible to liquefaction.

The following table depicts the ground motions that are likely to occur at the six study locations in the Delta at various return periods from all seismic sources.

TABLE 22 – Ground Motions for Return Periods of 100 to 2,500 Years in 2005 from all Seismic Sources (Seismology TM 2007, Table 5)

	Peak Ground Acceleration (g's)			
Delta Site	100 yrs	200 yrs	500 yrs	2,500 yrs
Clifton Court	0.22	0.29	0.40	0.66
Delta Cross Channel	0.15	0.19	0.25	0.37
Montezuma Slough	0.27	0.35	0.47	0.74
Sacramento	0.12	0.15	0.20	0.30
Sherman Is.	0.24	0.31	0.41	0.64
Stockton	0.13	0.17	0.22	0.32

The DRMS study also evaluated the hazard without considering Delta faults and found only a small reduction in potential ground motion over shorter return periods, further illustrating the importance of the Bay Area faults to the hazard in the Delta.

Past occurrences of Bay Area Delta levee disasters

While levees of Delta islands fail frequently, these occurrences typically are not on islands within the nine-county San Francisco Bay Area. Even with the Jones Tract levee failure, the island was not within the region. However, this failure almost caused the subsequent loss of both Mokelumne Aqueducts of East Bay MUD. Such occurrences are expected to occur more frequently based on an assessment of the Delta Risk Management Study (DRMS) and other research. See Appendix D and http://quake.abag.ca.gov/mitigation/disaster-history.html for more specific information on the Jones Tract failure.

Exposure and vulnerability of the Bay Area to Delta levee disasters

The Sacramento-San Joaquin River Delta and Suisun Marsh are vitally important to the Bay Area economy and environment. The region contains highly fertile agricultural land and provides a unique habitat to many estuarine animals. The Delta region contains critical infrastructure including pipelines, highways, and power and communication lines. The Delta is the hub of the California water system, providing water to 25 million people in the State and 3 million acres of farm.

2005 Present Day Seismic Risk

When an earthquake occurs, all Delta levees may be subject to ground shaking and potential failure simultaneously. If an earthquake is strong enough to cause the failure of one levee, it is likely that other levees with the same or higher vulnerability will also fail. It only takes the failure of one section of levee to flood an island. Levees to the west are more likely to fail where shaking is stronger than to the east.

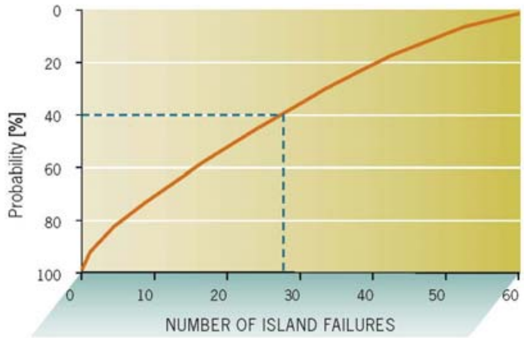

Figure: Probability of exceeding a number of simultaneous islands flooding due to earthquake events over a 25-year period [2005-2030] (DRMS 2008)

The seismicity of the Delta Region is characterized as moderate to high as a result of the active Bay Area faults. The USGS predicts a 62% chance that a magnitude 6.7 or greater earthquake will occur in the Bay Area in the next 30 years.

A simulated 7.2 earthquake on the Hayward fault is estimated to cause a mean number of 50 levee failures. This scenario does not account for the range in possible magnitudes, the various fault segments that could potentially rupture, or the possible distances from the epicenter to the Delta. In addition, an earthquake that ruptures to the north or south and moves towards the Delta will be more devastating than an event that ruptures in the middle of the fault and travels north and south, because of the build up of energy in the direction of wave travel. An earthquake on the Hayward fault has other implications for the region because it will also be widely damaging to the Bay Area, reducing our ability to respond to levee damage in the Delta.

2005 Present Day Seismic Consequences

The consequences of multiple levee failures as the result of an earthquake will be widespread and will impact every sector that relies on the Delta.

Public Health Consequences. The primary public safety concern is potential loss of life on flooded islands as a result of an earthquake. Approximately 10 fatalities can be expected every 100 years on average as a result of an earthquake. Impact on water quality was not specifically analyzed in the DRMS report.

Emergency Response and Levee Repair.
The following table depicts expected time to repair and dewater levee breaches.

Table 23 – Duration and Cost of Repair and Dewatering for Seismic Cases (DRMS 2008, Table 13-9)

No. of Flooded Islands	Estimated range of cost of repair and dewatering ($M)	Estimated range of time to repair and dewater (days)
1	43 – 24	136 – 276
3	204 – 49	270 – 466
10	620 – 1,260	460 – 700
20	1,400 – 2,300	750 – 1,020
30	3,000 – 4,200	1,240 – 1,660

*the range is provided for +/- one standard deviation of the mean

Export Disruption. Repair to damaged levees could take years following a major earthquake. When the levees fail, salt water from the Bay will flow back into the Delta to fill the voids left open by the damaged levees. Drinking water that is normally pumped from the Delta will be too saline for safe consumption and export of fresh water will be disrupted for a period of time until all the levees are repaired and sufficient fresh water can released from upstream to flush out the salt water. If 20 islands were flooded as a result of a major earthquake (~55% probability in the next 25 years), export of fresh water from the Delta could be interrupted for about a year and a half. Contra Costa Water District is particularly as risk because they lack alternative sources of drinking water outside of the Delta.

Economic Consequences. When multiple levees fail in the Delta, the cost will be borne by the entire state. In the DRMS study, the economic consequences are quantified in terms of the economic cost (net costs to the state economy) and economic impacts (value of lost output, lost jobs, lost labor income, lost value income and indirect business taxes). The DRMS study indicates that due to an earthquake economic costs will exceed $20 billion and economic impacts will exceed $12 billion once every 90 years on average. The economic consequences will depend primarily on number of flooded islands, which islands have flooded, and the month in which the initiating event occurs. ABAG estimates the 2005 value of property improvements on the Delta islands within Contra Costa County as $1.4 billion, and the 2005 value of the property itself as $1.1 billion – far less than the potential economic impact of loss of the water supply.

Ecological Consequences. For breach scenarios involving less than 10 breaches, a very small percentage of the total area of the vegetation types in the Delta are impacted. For breach scenarios with 20 breaches, greater losses are incurred for a vegetation types. Large numbers of delta breaches would also have significant impact on terrestrial wildlife because available habitat would be severely reduced.

Increasing Future Risks and Consequences

As the Delta moves ahead from 2005, several factors will drive changes that will affect the seismic vulnerability of the Delta. These include seismic activity, climate change, subsidence, and population growth and urbanization.

Seismicity. The Bay Area has experienced a period of relatively low seismic activity since the 1906 San Francisco earthquake. As stress continues to build in the earth, we may experience greater seismic activity in the region in the near future. The DRMS study assumes that seismic activity will increase by 10% in 2050, 20% in 2100 and 40% in 2200.

Climate Change. Rising sea levels as a result of global warming produce higher water levels on Delta levees as well as increase internal seepage, both of which will increase the probability that an earthquake will fail the levee. Warmer temperatures will also mean that more winter precipitation falls as rain rather than snow and more runoff will flow into the Delta earlier, adding to the demand on the levees. This study assumed that the levees would be raised to accommodate higher water, but does not assume any strengthening of the levees. Projections estimate that sea-levels will rise between 4 and 16 inches by 2050 and 8 inches and 4.6 feet in 2100.

Subsidence. The ground surface in areas of the Delta-Suisun that have peat soils are expected to continue subsiding if current management practices do not change. Projections for total subsidence are up to 3 feet by 2050, 8 feet by 2100 and 17 feet by 2200, varying across the delta depending on the thickness of the organic layer. These scenarios place additional load on Delta levees as the height of water being held by the levee increases. Seepage through some of the levees will increase due to this additional load, making levees more vulnerable to earthquake loads.

Population Growth and Urbanization. Forecasts indicate that the population of the Delta and Suisun islands will increase by about 160% and the population of the legal Delta will increase 128% between 2000 and 2030 under current policies. This will lead to increased material assets and economic activity in the Delta and Suisun area. In addition the population of the state is expected to increase by 61% between 2005 and 2050, creating more demand for drinking water in the state and greater consequence of levee failures.

Consequences. The risks the delta faces interact with each other, compounding the consequences. Rising sea levels and continuing subsidence will mean that when levees fail, there will be a bigger void that can be filled with water. Additional salinity intrusion into the Delta will require more time and water for flushing. The combination of these two effects will increase the height of water behind levees by about 4 feet by 2050 and 10 feet by 2100.

As demand for drinking water from the Delta and the population and economy of the Delta increases, the consequences of levees failure will continue to increase in the future. In addition, increasing risks in the future mean that levee failures will occur more frequently, result in more levees failures and longer recovery times, further increasing the impact of failure. Economic losses are expected to increase by about 200 percent by 2050 and by about 500 percent by 2100.

The following table demonstrates the increased frequency of levee breaches as a result of seismic events.

Table 24 – Percent Increased Frequency of Seismic Breach Events Under BAU (DRMS 2008, Table 14-17)

Year	Low Risk Scenario	Medium Risk Scenario	High Risk Scenario
2050	28%	35%	49%
2100	68%	93%	140%

Conclusion

The Delta levees are crucial to our state economy and drinking water system. The levees are extremely vulnerable to seismic risks. This risk is compounded when an earthquake on the Hayward fault fails levees while simultaneously causing significant damage in the Bay Area. Our ability to repair levees depends on our ability to transport goods and workers to the area. This will be difficult if transportation systems are damaged and resources become scarce. The Delta Risk Management Strategy (DRMS) clearly demonstrates that the levees as they are today are not sufficient to sustain the region for the next 100 years.

Other Concerns Not Addressed Directly as Part of This Plan

Heat

The Bay Area can have days that exceed 100°F. These heat waves would be more life-threatening if it were not for the common availability of air conditioning. Thus, this hazard is not dealt with directly as part of this Local Hazard Mitigation Plan. However, planning for such emergencies by transportation agencies is dealt with in INFR a-16.

Freezing

The Bay Area, particularly its crops, can be subject to extensive damage due to freezes. Freezing conditions also cause die back of vegetation that can become fuel for the subsequent fire seasons. This issue has been especially problematic for the Bay Area's eucalyptus trees.

Freezing conditions caused emergency conditions in 1970, 1972, 1973, 1990, and 2007.

This hazard is not something that can be easily depicted in map form. The hazard itself can be mitigated, however. Some available strategies are included in Local Hazard Mitigation Plan when dealing with the more general wildfire hazard.

Pandemic Flu

In 2009, the H1N1 flu pandemic has been declared a disaster to facilitate federal funds for local health department activities. While a disaster, mitigation for a pandemic flu is not included in this plan. However, planning for such emergencies by transportation agencies is dealt with in HEAL c-1.

Agricultural Pests

Several of the disasters in the Bay Area in the last few decades are related to insect infestation, particularly as they relate to agricultural production. For example, Contra Costa and San Mateo counties were declared disasters in the 1981 Mediterranean fruit fly infestation, and Santa Clara County was declared disasters in the 1989 Mediterranean fruit fly infestation.

When there is an agricultural emergency, it remains necessary to comply with CEQA. In addition, the State may issue special regulations for local governments. Policies related to agriculture and aquaculture instituted by county offices of the Agricultural Commissioner and county health departments do have a role to play, as identified in the following three strategies, and include ENVI c-1, ENVI c-2, and ENVI c-3.

Security-Related Threats

The focus of this mitigation plan and of DMA 2000 is on natural hazards. The Bay Area has never experienced a terrorism-related disaster. Man-made hazards are only addressed in this plan as they relate to natural hazards. For example many of the strategies in GOVT and INFRA relate to retrofitting and replacing critical facilities or installing security cameras which can serve the dual of mitigating against both natural and man-made disasters.

Summary Overview of Impacts of Natural Hazards on the Bay Area

Earthquake Impacts

The natural disasters with the largest potential impacts on the Bay Area are earthquakes. Most of the damage is due to ground shaking, with relatively little due to liquefaction and landsliding. For example, in the Loma Prieta earthquake, only 1.6% of the $6 billion in losses could be attributed to liquefaction[20], and an even smaller percentage to landsliding. Surface fault rupture can do significant damage to infrastructure systems, depending on the earthquake. (The fault that caused the Loma Prieta earthquake, for example, did not rupture the surface, so there were no losses associated with fault rupture in that earthquake.)

The extent of the impact of earthquake disasters can best be explained using various earthquake scenario events. For example, in a magnitude 6.9 earthquake on the entire Hayward fault (extending from San Pablo Bay to the border of Alameda and Santa Clara counties), ABAG has estimated over 150,000 uninhabitable housing units and 1,700 road closures. In 2003, the FEMA-developed HAZUS software only estimated 24,000 displaced households, a factor of 6 lower than the ABAG estimates. Part of this discrepancy is due to uncertainty on the impact on wood-frame apartments with parking in the ground floor ("soft-story" apartments). HAZUS estimates the total losses for that earthquake as only $23 billion (versus actual losses of over $40 billion in the Northridge earthquake, a smaller magnitude earthquake with a less vulnerable building stock).

The Bay Area Economic Forum produced a 2002 report on the impact of this earthquake on *Hetch-Hetchy Water and the Bay Area Economy*[21], estimating that the losses associated with failure of that system alone would be $17.2 billion. Finally, the HAZUS software predicts from 100-700 fatalities in that earthquake scenario, depending on the time of day. These estimates are difficult to evaluate, particularly because they are so tied to the vulnerability of particular systems. For example, fatalities in the BART tube alone could exceed that value if the tube were to rupture catastrophically. Obviously, the current HAZUS estimates are inadequate. Thus, as specified in the ABAG Annex to this plan, ABAG will be working to develop different ways to either refine those estimates or develop alternative ways to express losses and risk. As mentioned earlier, RMS proprietary software used to estimate residential losses produced an estimate of $90 billion given a repeat of the 1868 Hayward earthquake on the southern Hayward fault in 2008, versus an estimate of only $8 billion from the 2003 HAZUS run. This MJ-LHMP estimates that the RMS estimate is much closer to reality. See ABAG Annex mitigation strategy GOVT-e-2. Any remaining gaps in knowledge following that effort will be identified as part of that effort. The goal is for future loss estimates to be city-specific. Interestingly, the work conducted jointly on soft-story housing in Oakland focused not on dollar damage losses, but on issues of habitability and community-level impacts, such as loss of property tax and business tax.

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[20] Holzer, T.L., ed., 1998. "Introduction" in ***The Loma Prieta, California, Earthquake of October 17, 1989 – Liquefaction.*** U.S. Geological Survey Prof. Paper 1551-B: Reston, VA, pp. B4.

[21] See http://www.bayeconfor.org/pdf/hetchhetchyfinal2.pdf to view the entire report.

Weather-Related Impacts

Past flooding losses have been significant, but not as large as for earthquakes. For example, the January 1997 floods resulted in $1.8 billion in total damage in California, while the El Nino storms of early 1998 resulted in $550 million in losses in the entire state, including both flooding and landslides impacts. FEMA documents over $98 million in total repetitive losses in the Bay Area that have been paid by their insurance program since its inception, most of which (over $65 million) has occurred in Sonoma County. However, since 6.4% of the urban land in the Bay Area is within the 100-year flood plain and climate change may increase the size of spring runoff, future losses could be more significant than in the past. Note that some of the repetitive loss claims have occurred in areas outside of the Q3-mapped 100-year flood plain, making it clear that other areas are susceptible to flooding, but to a lesser extent.

Losses from landslides are typically lower than associated flooding. However, in the El Nino storms of early 1998, USGS documented approximately $150 million in losses due to approximately 300 landslides that occurred in the Bay Area and Santa Cruz County[22]. The landslides ranged in size from a 25 cubic meters failure of engineered material to a reactivation of the massive (13 million cubic meters) Mission Peak earthflow complex in Alameda County.

The largest urban-wildland fire in the Bay Area, the 1991 fire in the East Bay Hills, resulted in $1.7 billion in losses. In that fire, 3,354 family dwellings and 456 apartments were destroyed, while 25 people were killed and 150 people were injured. While in the 2005 MJ-LHMP, it was assumed that it was is unlikely that any single fire disaster in the Bay Area would exceed that fire in total losses, that assumption can no longer be made. A combination of increasing property values in wildfire areas, increasing fuel, and climate change all contribute to this change. However, these losses are many times smaller and more localized than that anticipated from a disastrous earthquake.

The report on *Hetch-Hetchy Water and the Bay Area Economy* discussed earlier hints at the importance of water to the region and the potential impacts of drought and population growth. That report notes on page 5 that:

> Based on conditions during the most recent drought period, SFPUC now has determined that the maximum quantity of water it can reliably deliver to its customer base is 239 mgd annually. However, actual demand in 2000-2001 was nearly 260 mgd, and it is generally understood that the SFPUC system is operating in excess of its assured supply capacity and approaching its actual delivery capacity.
>
> Total demand for Hetch Hetchy water is expected to grow to 303 mgd in 2030 and 310 mgd by 2050. Absent a significant expansion of the system, the shortfall relative to assured supply will therefore increase from 21 mgd presently to 64 mgd within 30 years and 71mgd within 50 years.

M.Cubed conducted an economic assessment of long-term drought on EBMUD's customers. The original study estimates the costs to all EBMUD customers of $186 million with a rationing level

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[22] Godt, J.W. , ed., 1999. "Introduction" in ***Maps Showing Locations of Damaging Landslides Caused by El Nino Rainstorms, Winter Season1997-98, San Francisco Bay Region, California***: U.S. Geological Survey Misc. Field Studies Map MF 2325-A-J: Reston, VA. See http://pubs.usgs.gov/mf/1999/mf-2325/.

of 10% to $1.14 billion with a rationing level of 25% during each year rationing is in place.[23] All values are in 2002 dollars. The estimates are contained in the following table. Water shortage costs equal consumer surplus losses for residential, institutional, and irrigation customer classes plus regional value added losses for commercial and industrial customer classes. Regional value added losses equal the sum of losses to labor income, proprietor income, profits and property income, and indirect business taxes.

TABLE 25 - East Bay Municipal Utility District Water Shortage Costs, 2040 Level of Development - (Source: M.Cubed, March 2008, Table 1)

	Water Shortage Cost (in $ millions per year of shortage)		
Rationing Level	**10%**	**15%**	**25%**
Single Family	24.2	47.5	150.7
Multifamily	6.4	12.1	34.2
Commercial	94.5	142.3	786.2
Industrial	57.7	86.8	145.1
Institutional	0.5	0.8	1.7
Irrigation	2.6	5.6	24.6
TOTAL	**186.0**	**295.1**	**1,142.5**

Most Bay Area water districts develop long-term water supply and management plans, including urban water shortage contingency analyses. ABAG will be working with water districts and others on this issue, as specified in the ABAG Annex, Mitigation Strategy INFR-d-4, ENVI-a-4 and ENVI-a-5.

Catastrophic failure of a dam in the region would result in huge losses. While damage losses have not been quantified, the areas subject to dam failure inundation include 18.1% of the urban land in the Bay Area.

The Delta levees are crucial to our state economy and drinking water system. Delta levee failures have occurred in the past. The Holland and Webb Tracts levee breaks in 1980 impacted Contra Costa, Sacramento, and San Joaquin counties and resulted in $17.4 million in damage. The levees are extremely vulnerable to seismic risks. This risk is compounded when an earthquake on the Hayward fault fails levees while simultaneously causing significant damage in the Bay Area. Our ability to repair levees depends on our ability to transport goods and workers to the area. This will be difficult if transportation systems are damaged and resources become scarce. The Delta Risk Management Study (DRMS) clearly demonstrates that the levees as they are today are not sufficient to sustain the region for the next 100 years.

Lack of understanding of potential impacts of global warming on the region and other hazards leads to further uncertainties in estimating weather-related losses and impacts. Some of these interrelationships are described in ***Chapter 7*** *– Environment*.

Again, more work is needed in estimating the impacts of weather-related disasters. Thus, as specified in the ABAG Annex to this plan, ABAG will continue to work in developing different

[23] See http://www.ebmud.com/water_&_environment/water_supply/water_supply_management_program/economic_analyses/Cost%20of%20Water%20Shortage.pdf to view full memo.

ways to express losses and risk. Part of this effort is related to coordination with the Bay Area Integrated Water Management Plan effort described in the section on Drought in this Appendix. See ABAG Annex mitigation strategy GOVT-e-2. Any remaining gaps in knowledge following that effort will be identified as part of that effort. The risk and loss estimates will be city-specific.

Data Limitations

In the previous plan, it was noted that there were major faults in the Bay Area, such as the West Napa fault and the Maacama fault, for which there was insufficient information to produce probability estimates. Probability estimates for these faults was developed in the 2008 USGS Working Group on Earthquake Probability and has been included in the update to this plan in ***Table 1***.

While many of the faults in the Bay Area are well studied, there is still much that is unknown about them, including how much they will slip in the location of a pipeline crossing during a future earthquake or the exact location of a fault trace. Furthermore while the slip zone in rock is very localized, in thick soils the zone can be quite wide when the surrounding soil is dragged along with the fault, called warping. Much study continues to be done in this area, including the development of a fault displacement hazard assessment

Liquefaction susceptibility and earthquake induced landslide maps were only available for a portion of the Bay Area in the previous plan. No new updates are available at this time. USGS and CGS are developing hazard maps for more areas as further research is completed. When these maps become available ABAG will incorporate them into its hazard analysis.

As of February 2005, a tsunami map of a portion of the Bay Area ocean coastline from San Gregorio in San Mateo County to Lincoln Park in San Francisco has been published. The State of California Governor's Office of Emergency Services (OES) has worked to finalize this map for the rest of the Bay Area Ocean coastline since 2005. An updated map was finalized in June 2009 and has been incorporated into ABAG's hazard analysis.

Probability information is still not available for the Bay Area tsunami hazard. ABAG and others are working with State OES to encourage more mapping that has an estimate of probability associated with it. OES and the California Geological Survey will be discussing this issue in a meeting tentatively scheduled for the fall of 2005. The tsunami hazard map is not a hazard map, but an evacuation planning map, because it is not based on probabilities. ABAG continues to work with OES and the affected counties and hopes to make additional maps of this type available in the coming months.

As of June 2010, updated FEMA flood zone maps are not available for San Mateo County. Updated maps are expected to be released in September 2010.

How Has Understanding of Hazards and Risks Changed Between 2005 and 2010?

The previous sections focus on describing the most significant natural hazards affecting the San Francisco Bay Area related to earthquakes (faulting, shaking, liquefaction, landslides, and tsunamis) and weather (fire, flooding, landslides, drought, and climate change), as well as dam and levee failure.

Progress

The most significant change in this analysis in the past five years has been the recognition of significance of the impacts that climate change can potentially have on weather-related hazards. Thus, Chapter 7 – Environment has a section that focuses entirely on this issue of potential climate change impacts and includes mitigation strategies that mitigate climate change itself.

ABAG has also focused on determining hazard exposure of private property and land use changes, which has resulted in newly incorporated Appendices E and F.

The other significant innovative change and improvement in this assessment is the function-by-function integration of risk exposure into the assessment of individual functional systems. This includes, for example, a review of current data and programs related to cripple-wall hazards associated with single-family homes and soft-story issues related to multifamily housing. The assessment goes beyond a simple modeled total of road closures or estimated housing losses to develop mitigation strategies targeted at reducing the *causes* of those risks. Each of these assessments is included in the MJ-LHMP Chapters, for this assessment is much more useful than simple hazard exposure calculations, or even data on expected dollar losses, in evaluating the usefulness of various mitigation strategies. The development of these functional assessments was made possible by the series of collaborative efforts among the cities, counties, and special districts of the Bay Area during the past five years. A grant from FEMA through CalEMA, collaboration with ABAG Plan Corporation's Sewer Smart efforts, and specifically allocated funding from MTC has made Chapter 1- Infrastructure much more complete and comprehensive than it would have been without this additional funding targeted and water, wastewater, and transportation systems.

Gaps

Not all hazards have quantitative probabilistic information. The Bay Area local governments participating in this MJ-LHMP all plan to continue to work together to develop and share risk information. In addition, for example, USGS, the California Geological Survey, CalFIRE, and CalEMA also are working on mapping and risk assessments of some, but not all, of these hazards that will continue to improve these assessments.

ABAG consulted all of the authors of hazard maps used in the 2005 plan and determined if there was a more recent version of those maps or probability information suitable for inclusion in this plan.

- ♦ CGS is developing new fault hazard maps that include estimates of fault displacement that should be available within the next five years.

- The USGS and CGS shaking potential map has been updated based on revised earthquake probabilities, but it does not account for differences in soil and rock type. Thus, the earlier shaking potential map continues to be used. Newer maps should be available in five years. (The earthquake probabilities on page C-3 in this plan have been updated, however.)
- The CGS maps of earthquake-induced landslides have not been completed. As noted, we have a mitigation strategy specifically noting our willingness to provide support to CGS in this effort when they approach any of us to obtain parcel-specific studies.
- In 2006, USGS and others completed an update of the liquefaction susceptibility map for the inner Bay Area. This map replaced the 2000 susceptibility map in areas where it was updated.
- By the next edition of this plan, CalEMA and CGS should have published tsunami hazard mapping, not just tsunami evacuation maps, which can be used for mitigation planning.
- The CalFIRE wildfire threat maps have been updated, as have the fire perimeter maps. But the WUI fire threat map has not. It continues to show a hazard in the areas next to the Bay with high groundwater that the cities bordering the Bay believe is an overestimation of the threat.
- Flooding Q3 maps have been replaced by D-FIRM maps in all counties except San Mateo, where they have not yet been released by FEMA.
- Landslide hazards assessment continues to be underfunded by USGS. While some promising modeling is on-going, this modeling has not yet resulted in mapping that is more useful to this plan than the maps used in 2005. ABAG grant applications to USGS for funding were denied.
- ABAG did a thorough literature search and was unable to locate any updated information on the probability of drought. As noted earlier, the U.S. Department of Agriculture is beginning to take initiative in this area.

As noted earlier, local governments are suffering in the midst of a recession that has impacted them directly – and that has been made worse by the forced “take away” by the State of California so that the State can balance its budget. Thus, capital improvements budgets have decreased and planning departments have been hit with furloughs and layoffs. Many existing and on-going mitigation efforts have been slowed.

But we have been creative. Through collaborations with the Earthquake Engineering Research Institute Northern California Chapter and the Structural Engineers Association of Northern California, ABAG is continuing to collect valuable information on the locations of vulnerable privately-owned structures through the use of volunteers. The use of volunteers made the collection of a comprehensive review of Oakland’s 3,000 multifamily buildings feasible with the assistance of a $100,000 grant from FEMA through CalEMA. The status of those efforts is incorporated into Chapter 3 – Housing and Chapter 4 – Economy. ABAG has a list of unreinforced masonry buildings in the region that appears to be out of date. Unfortunately, local governments did not keep records of specific URM buildings once they had undergone minimal life-safety retrofits. Thus, there remains a large discrepancy between data compiled by the State Seismic Safety Commission and individual cites.