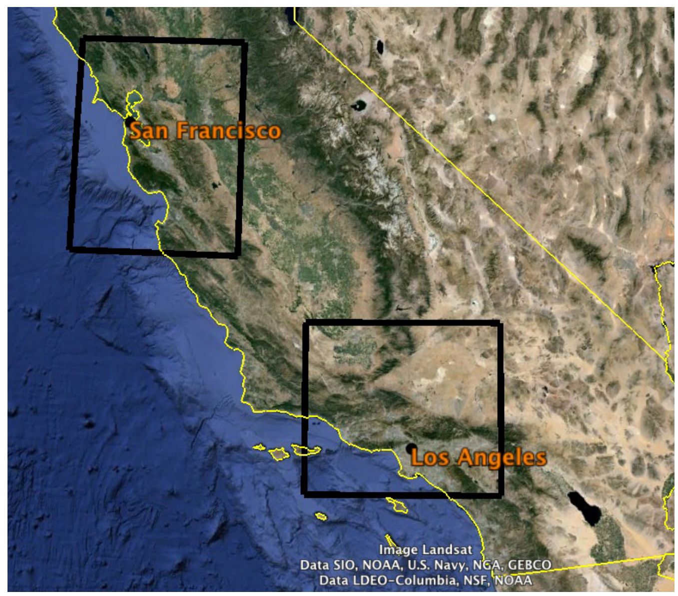
Name ______________________________

Determining Earthquake Probabilities

A magnitude 7.0 or greater earthquake has not occurred in either the San Francisco or the Los Angeles area for over 100 years. But we know they do occur (e.g. 1906). Are such events worth worrying about? How do scientists determine the probability of such events occurring in the next year? In the next 30 years?

Learning objectives for this activity:

- *To use data to determine the probabilities of earthquakes of various magnitudes in the San Francisco area and the Los Angeles area (optional).*
- *To compare your results to the regional earthquake probability map for California and assess the regional earthquake hazard along this plate boundary.*



You will use the history of earthquakes in the San Francisco (and Los Angeles) areas[1] to determine the probability of occurrence of earthquakes of various magnitudes over various time periods. The areas are delineated in the black boxes at right.

The data come from two searchable databases. For each search, the investigator enters the area, the time period, the magnitude range, and the depth-to-hypocenter range to be searched. The parameters used here are listed below:

	San Francisco area	Los Angeles area
Latitude range	36.25 - 38.75°N	33.5-35.5°N
Longitude range	120.75 - 123.25°W	116.75-119.75°W
Date range	01/01/1983 – 12/31/2012	01/01/1983 – 12/31/2012
Magnitude ranges	2.0-2.9, 3.0-3.9, up to 9.0-9.9	1.0-1.9, 3.0-3.9, up to 9.0-9.9
Depth range	All	All
Data source	United States Geologic Survey	Southern California Earthquake Center
Searchable database	http://neic.usgs.gov/neis/epic/epic_rect.html	http://www.data.scec.org/eq-catalogs/date_mag_loc.php

On the spreadsheet for the San Francisco area (which you will complete with the class), the number of earthquakes in each magnitude range (**Column A**) has been entered in **Column B**.

[1] Google Earth Imagery with data from SIO, NOAA, U.S. Navy, NGA, GEBCO, LDEO-

In **Column C**, calculate the average number of earthquakes per year that occurred in each magnitude range. Some rows have been completed for you.

In **Column D**, calculate the mean recurrence interval (MRI) for each magnitude range for up through magnitude 6.0-6.9. The MRI is defined as the average time between earthquakes, and it is calculated by taking the reciprocal of the average number of earthquakes per year:

$$\text{MRI} = \frac{1}{\text{average number of earthquakes}}$$

> Example: The database records an average of 57.2 earthquakes of magnitude 2.0-2.9 each year in the San Francisco area. The MRI (1/57.2) is 0.017 years, which is equivalent to an average of one earthquake every 6 days.
>
> Your turn: What is the approximate MRI in days for earthquakes in the San Francisco area with magnitudes of 4.0-4.9?
> a) Less than 1 day b) 68 days c) 113 days d) 256 days e) 340 days

But what about MRIs for earthquakes of magnitudes 7.0 and greater? Earthquakes of this size have not occurred over the 30-year study period, and thus we do not have enough data to determine the MRI by taking the reciprocal of the average number of earthquakes. However, it is possible to extrapolate MRIs for these large earthquakes by using data for the lower-magnitude earthquakes as follows:

- On the graph, plot the MRI (**Column D**) for each magnitude range for which you have data. Note that the vertical scale is logarithmic, and the MRI increases by about a factor of 10 for each increase in magnitude size. Some have been plotted for you.
- Sketch in a best-fit line to the data and extend it to cover the magnitude ranges for which you do not have data.
- Read off extrapolated MRIs for those magnitude ranges and enter them to complete Column D. One has been entered for you.

In **Column E**, determine the probability of earthquakes of each magnitude range occurring in one year. Probability can be expressed as either a fractional probability between 0 and 1.0, or as a percentage from 0 - 100% (by multiplying the fractional probability by 100). In the worksheet you will record both.

- For earthquakes with MRIs of one year or less: The probability of these earthquakes occurring in any one year is 1/1 = 1.0 or 100%. Record these values for the appropriate magnitude ranges in Column E. The first row has been done for you.
- For earthquakes with MRIs greater than one year: Fractional probability = 1/ MRI and then multiply by 100 to get % probability. *Note that this is equal to the average # of earthquakes per year. But using the 1/ MRI method allows calculation of probabilities for earthquakes that have not occurred over the study period because we have extrapolated MRIs.*

Use the 1/MRI method to complete Column E.

We have just calculated *annual* probabilities of earthquakes.

But what about longer time periods?

The probability of an earthquake occurring over any time period is 1 (or 100%) minus the probability of the earthquake not occurring over that time period (either it happens or it does not).

So consider a two-year time period. For an earthquake to not occur over two years, two conditions must be met:

1) The earthquake must not occur in the 1st year, *and*
2) The earthquake must not occur in the 2nd year.

To get the combined probability, we multiply the individual probabilities of the two events.

Thus we need to determine the probability of an earthquake not occurring in one year.

In **Column F,** determine the probability of each earthquake magnitude *not* occurring in a year. This is simply 1.0 (or 100%) minus the probability of that event occurring in a year (Column E). That is, either it occurs or it does not! Some have been completed for you.

Now we have the information we need in order to determine earthquake probabilities for any time period. For example:

What is the probability of a 6.0-6.9 earthquake occurring in the San Francisco area in the next **thirty** years? To determine this:

- Determine the annual probability of such an earthquake not occurring (0.90 from Column F). Then,

- The probability of it not occurring in **two** years is

  $0.90 \times 0.90 = 0.90^2 = 0.81$ or 81%, and

- The probability of it not occurring in **three** years is

  $0.90 \times 0.90 \times 0.90 = 0.90^3 = 0.729$ or ~73%, and

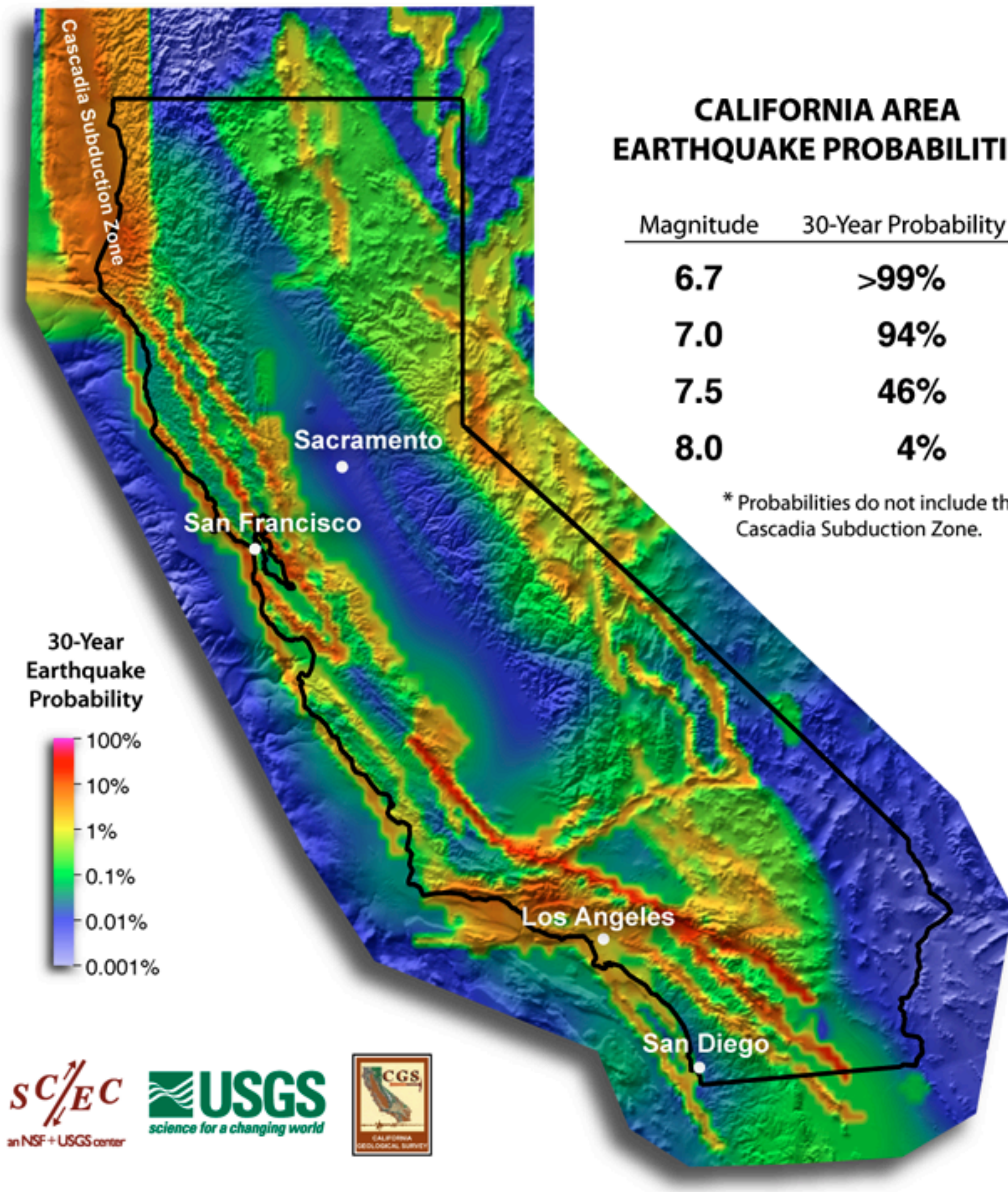
- The probability of it not occurring in **thirty** years is

  $0.90^{30} = 0.042$ or ~4%, and

- The probability of a 6.0-6.9 earthquake occurring in the San Francisco area in **thirty** years is

  1 – 0.042 = 0.958 or ~ 96%

This is how scientists calculate earthquake probabilities (see figure below[2]) – and thus quantify the hazard.



QUESTIONS

[2] CA Earthquake Probability Map
Credit: USGS, California Geological Survey, Southern California Earthquake Center
Source: http://www.scec.org/core/public/sceccontext.php/3935/13661/
Accessed December 2013

1. No earthquake with magnitude 7.0-7.9 has occurred in the San Francisco area over the 30-year study period.

    a. What is the probability of an earthquake of magnitude 7.0-7.9 occurring in the San Francisco in the next 30 years? Show your work.

    b. Do you think this probability is high enough to warrant concern? Why or why not?

2. Suppose that a particular area has a MRI of 30 years for earthquakes of M = 6.0-6.9. Suppose a M=6.7 earthquake occurs in that area this year. How does this affect the probability of such an earthquake occurring next year?

3. The statewide probability map suggests that overall, there is a 99% chance of a damaging M=(6.7 or greater) earthquake occurring somewhere in the state in the next 30 years. Should resources for earthquake preparedness be spread evenly across the state? Support your position with information from this unit.

Further applications (optional)

4. Use the provided spreadsheet and graph to repeat the analysis for the Los Angeles area (33.5-35.5°N / 116.75-119.75°W). Again, numbers of earthquakes for each magnitude range are filled in for you.

5. What is the probability of a magnitude 7.0-7.9 earthquake in the Los Angeles area in the next 30 years? How does this compare to what you calculated for a magnitude 7.0-7.9 earthquake in the San Francisco area?