Appendix L—Estimate of the Seismicity Rate and Magnitude-Frequency Distribution of Earthquakes in California from 1850 to 2011

By K.R. Felzer[1]

Introduction

Seismicity averaged across the State of California, or within any large region therein, has been found to robustly follow the Gutenberg-Richter magnitude-frequency distribution (Gutenberg and Richter, 1944; Felzer*,* 2006; Hutton and others, 2010). Figure L1 shows the *b* value for the magnitude-frequency distribution in California calculated by using catalogs with different minimum-magnitude cutoffs and different time periods.

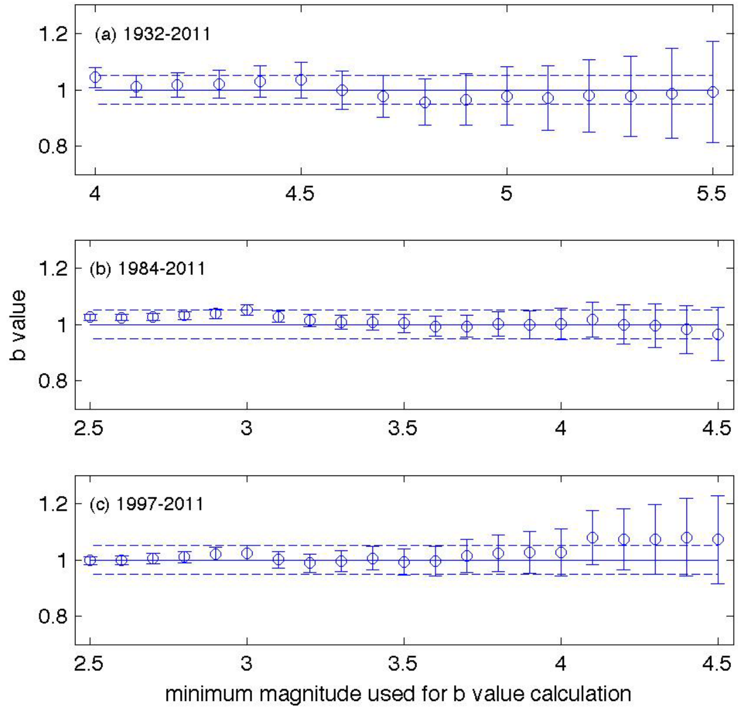

Figure L1. The Gutenberg-Richter *b* value calculated for the Uniform California Earthquake Rupture Forecsat region by using different minimum-magnitude thresholds and different time eras. A, data for 1932–2011; B, data for 1984–2011; C, data for 1997–2011. All values agree with a *b* value between 0.95 and 1.05.

---

[1] U.S. Geological Survey.

All values are consistent with a b value between 0.95 and 1.05. The best and most complete data set is from 1997 to 2011. This data can be considered to be nearly 100 percent complete to $M4$ throughout the region (Felzer, 2008). A minimum magnitude of 4.0 gives a b value of 1.03 with a 98-percent confidence range from 0.94 to 1.11. Most of the State is far more complete than that, however; appendix M (this report) indicates that more than 95 percent of the State is complete to $M2.6$ from 1997 to 2011. By using the 1997–2011 data with this minimum magnitude, I calculated that b=0.999, with a 98-percent confidence range from 0.982 to 1.015. Thus, for the calculations in this report, it was assumed that b=1, with a confidence range from 0.98 to 1.02. For the purposes of these calculations it was also assumed that the magnitude-frequency distribution ends abruptly at some M_{max} because this is a simple null hypothesis that is not refuted by global data (Burroughs and Tebbens, 2002).

Average annual seismicity rates for time periods 1850–2011 (historical and instrumental catalog) and 1984–2011 (modern instrumental catalog) have been compiled for the entire Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3) study area and for the northern and southern parts of the study area. Catalog completeness estimates for these rate calculations were determined using the thresholds calculated by Felzer (2008) for different regions (tables L1–L9), with the exception that the completeness threshold for 1850–1865 was dropped from 8.0 to 7.4, based on reassessment that an $M>7.4$ earthquake would probably have been felt over a sufficiently wide area of the State to have been noted, despite the sparse population. The average 1850–2011 rate of $M\geq5$ earthquakes was calculated, with corrections for rounding and magnitude error as detailed in Felzer (2008); these corrections require the assumption of a Gutenberg-Richter distribution, b value, and M_{max}. Direct, raw rates in different magnitude bins also were calculated; these rate calculations do not require assumptions. The two types of rate calculation are explained in detail below. All of the rates calculated here are for earthquakes at <35 km depth; the rate of deeper earthquakes in the UCERF region is estimated to be 0.1 $M\geq5$ earthquakes per year.

Calculation of the mean $M\geq5$ rate is detailed below. Results for 1850–2011 are given in table L10, and results for 1984–2011 are given in table L11.

The catalog is corrected for magnitude rounding and magnitude errors by using methods by Felzer (2008).

- The number of earthquakes greater than or equal to the completeness magnitude, Mc, is counted for each completeness era.
- Each count is converted into a rate of $5\leq M\leq M_{max}$ earthquakes/year by using the Gutenberg-Richter distribution with an assumed b value.
- The $5\leq M\leq M_{max}$ rates for each era were averaged together with each era weighted linearly by its duration. This method contrasts with the Weichert (1980) method used in National Seismic Hazard Maps and in UCERF2 in which each era is weighted by the number of earthquakes it contains. If the underlying rate is the same in each era, the Weichert (1980) method produces a more accurate result; however, if the seismicity rate changes with time, then the Weichert (1980) method produces a result that is heavily skewed towards the instrumental era. In UCERF2 the rate calculation used the traditional Weichert (1980) method and an averaged Weichert (1980) method in which Weichert calculations made over three different time periods were averaged together. In this investigation dropping the Weichert (1980) routine all together from the calculations results in more weight being placed on the historical data and produces a higher seismicity rate than that calculated for UCERF2. The Weichert (1980) method is dropped completely to reflect

findings that seismicity rates most likely do change with time; for example, the well-documented decrease in seismicity rate since the late 1920s in the San Francisco Bay Area (Buffe and Varnes*,* 1993) and the seismicity-rate changes in the Santa Barbara Region and Imperial Valley Region (Appendix Q, this report).

Calculation of direct count rates is as follows.

1. Direct-count rates are calculated for $M\geq4.5$ earthquakes in the instrumental era (1932–present). These numbers are provided with the caveat that this era is incomplete for earthquakes $M<6$. The smaller earthquakes are missing, in particular, in the more poorly instrumented areas of the State and in the aftermath of large earthquakes, when active aftershock sequences overwhelm the recording system.
2. The total number of earthquakes occurring in each half-magnitude unit are counted.
3. No magnitude-rounding or error corrections are performed, because these require assumptions about the magnitude-frequency distribution. Likewise, the counts given here are incremental, not cumulative, so a value of M_{max} did not need to be assumed.

As noted above, calculation of the mean $M\geq5$ rate requires a value of M_{max}. For continental transform boundaries like California, Bird and Kagan (2004) find a corner magnitude of 8.01 -0.21 +0.47. The Grand Inversion (Appendix N, this report) contains the possibility of magnitudes as large as 8.5, but the magnitude-frequency distribution is tapered such that *M*8.5 earthquakes are extremely unlikely. For this investigation M_{max}=8.25 was used as the maximum of a pure Gutenberg-Richter distribution, with a sharp cutoff for the purposes of the calculations.

Errors for all of the rates calculated with a stationary Poissonian function are given in the tables. For the mean $M\geq5$ rate calculation, separate uncertainties are calculated for each completeness era, producing a lowest and highest possible rate (at 95-percent confidence, two-tailed) for each time period. These lowest and highest rates are then averaged together with weighting by the length of the time period that each represents, in the same way that the rates from each completeness era are averaged together. The resulting confidence intervals represent the range of potential underlying seismicity rates for each catalog that is being analyzed. Note that this is not the same as the uncertainty on the true long-term rate because the Poissonian errors do not consider the possibility of seismicity rates varying with time, which, as noted above, probably occurs in California. As an additional test, decadal time periods in southern California and in the whole State from, 1932 to 2011 were examined, and more variation was found from decade to decade than would be expected from a stationary Poissonian function. This variability indicates earthquake clustering over long time periods.

In UCERF2, the problem of long-term variability was addressed with ETAS modeling, in which earthquakes were allowed to be as large as *M*8.3 (Felzer*,* 2008). This modeling captures only variability caused by normal aftershock triggering. To allow for the possibility that other sources of variability may exist, and that aftershock parameters may change under certain circumstances, a more empirical approach is taken here by using seismic rate variability from around the globe. It is presumed that California may show variability in seismicity-rate that is similar to seismically active areas elsewhere. Different areas of the globe were treated as snapshots of behaviors that might be seen in California at different points in time—in other words, space was used as a proxy for time. The global National Earthquake Information Center (NEIC) catalog, which is available down to *M*4.5 from 1973,was used in this investigation. The immediate aftershock zones of $M\geq8.5$ earthquakes were removed from this catalog (removing all earthquakes from the aftershock area, whether they occurred before or after the mainshock) because mainshocks larger than this are not expected within California. The following procedure was then used:

1. A random earthquake is selected from the global catalog, and a 1,400 by 100 km box is drawn around that earthquake. If the region is at least 90 percent as active as the UCERF region (from 1973 to 2011) then it is saved as a sample region. This sample is removed from the catalog, and a new random sample is drawn until all regions have been used.
2. The number of earthquakes occurring each year in each sample region is tabulated
3. All of the time series are normalized to the same mean rate. Note that this step decreases variability and makes the answer more conservative**.** This step was taken, however, because there is no justification for assuming that every region has the same long-term rate as California, and real regional long-term rates are not well known.
4. Sample regions are selected at random (with replacement). Each time a region is sampled, its entire time series of annual counts is added to the end of the simulated time series. The entire time series of a region is used every time it is sampled in order to preserve correlation in seismicity rates that may occur from year to year. The time series are strung together to achieve a total time series of 10,000-yr lengths (see example covering 500 years in figure L2).
5. The 10,000 year time series is broken into consecutive 161-year-long periods (the length of the 1850–2011 California record).
6. The exercise is repeated 20 times.
7. The results are used to make an empirical distribution of the rates that might be seen in individual 161-year periods for one true long-term mean.
8. The distribution in (7) is used to back out the distribution of long-term means that is consistent with the 1850–2011 observation of 7.9 $M \geq 5$ earthquakes/year. This is done by stepping along the distribution in (7), normalizing the distribution so that each point equals 7.9, and then taking the mean of each of the normalized distributions.

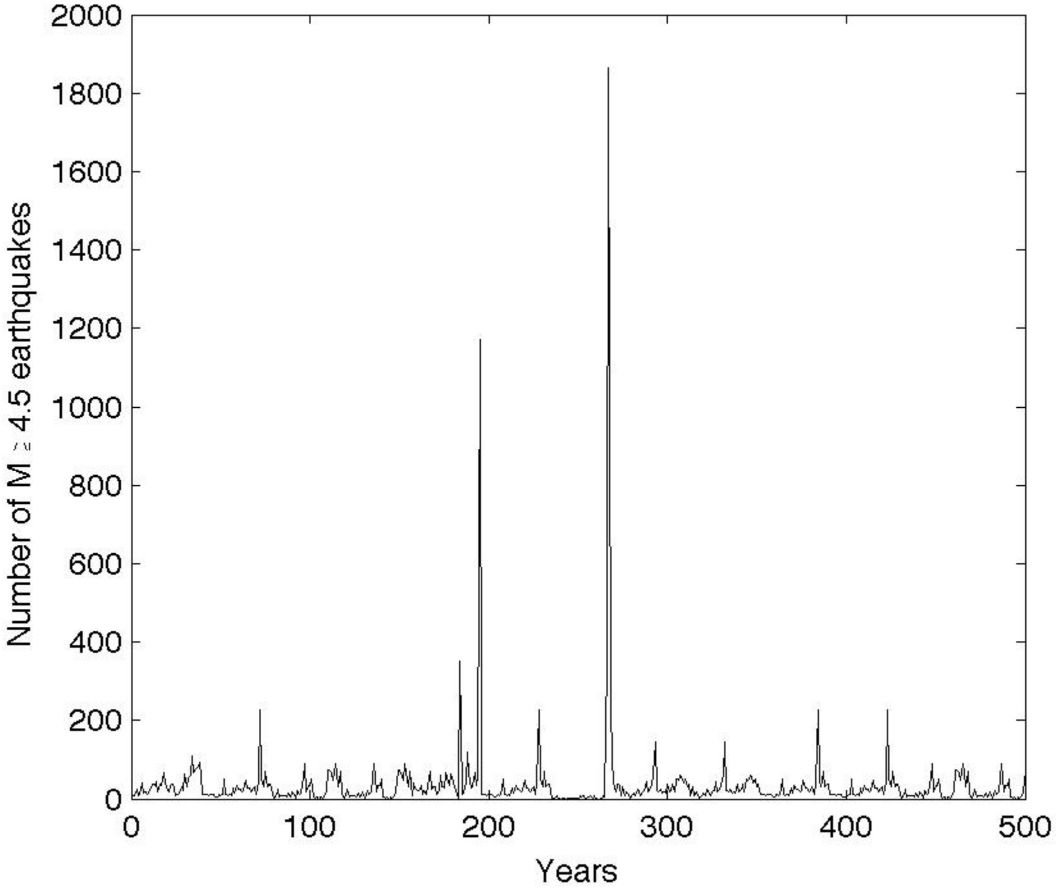

Figure L2. Graph showing sample 500-year time series produced by randomly stringing together different 38-year time series from the global record, and described in the text. Results are used to empirically estimate how short-term seismicity rates observed in California might compare to longer term seismicity rates (the global analog method).

If the Working Group on California Earthquake Probabilities precedent for model logic-tree branches is followed, weights of 0.2, 0.6, and 0.2 would be placed on the 5-, 50-, and 95-percentile positions of the distribution of the global analog long-term means, respectively. The result would be a weight of 0.2 on 6.5 $M \geq 5$ earthquakes/year, a weight of 0.6 on 7.9 $M \geq 5$ earthquakes/year, and a weight of 0.2 on 9.7 $M \geq 5$ earthquakes/year. There is paleoseismic evidence, however, that the rate of large earthquakes seen over the last 161 years in California is below the long-term mean (Biasi and Weldon, 2009). Based on this, the final rates are assigned as 0.1 on 6.5 $M \geq 5$ earthquakes/year, 0.6 on 7.9 $M \geq 5$ earthquakes/year, and 0.3 on 9.7 $M \geq 5$ earthquakes/year. The 95-percentile two-tailed confidence interval on the long-term mean seismicity rate in California obtained by using the global analog method is 6.2 and 9.9 $M \geq 5$ earthquakes/year (that is, these are the values at the 0.025 and 0.975 percentiles of the empirical distribution).

In addition to using the global analog method to estimate the error on the preferred statewide rate, it was used to estimate uncertainty on each of the direct-count rates, for the whole State and for specified regions. This is done so that each of these rates can be accompanied with confidence bounds on the true long-term, magnitude-specific mean rate, which can be used to evaluate the final UCERF model. For the subregions (northern California, southern California, Los Angeles, and San Francisco), proportionally smaller global analog regions are used. Because the direct-count rates for $M<6$ earthquakes are based on an incomplete data set, the earthquake rates for $M<6$ earthquakes are increased to complete rates estimated using the Gutenberg-Richter magnitude distribution with $b=1$ before calculating the global analog. Stationary Poissonian error must also be considered in the calculation of the direct-count rates. Thus, the confidence intervals given in the last column of tables L12 through L16 are the outermost confidence bounds encompassing the stationary Poissonian, global analog, and catalog incompleteness errors. For example, there are 1,021 $4.5\leq M<5$ earthquakes/year in the full UCERF3 1932–2011 catalog. The stationary Poissonian confidence interval on this value is 948–1,067. This value translates to an earthquake rate of 12.7 earthquakes/year with a Poissonian confidence interval from 12 to 13.5 earthquakes/year. However this data is incomplete below $M6$,, and using the rate of $M\geq6$ earthquakes/year and the Gutenberg-Richter magnitude-frequency relationship with $b=1$ gives a rate of 15.8 earthquakes/year. This rate is used as a basis for the global analog exercise, and it produces a range of possible long-term mean rates from 13.3 to 17.9 events/year (95 percent confidence). Combining the different confidence intervals and estimates, result in a 95-percent chance that the long-term mean rate of $4.5\leq M<5$ earthquakes in California is between 12 and 19.4 events/year. Full results are given in tables L12 through L16.

Table L1. Vertices, in latitude and longitude, of the polygons that define the different California regions used for the magnitude-of-completeness calculations.

[Vertices are given consecutively, in the clockwise direction]

Region	Latitude/longitude limits
California	43.0, -125.2; 43.0 -119.0; 39.4, -119.0; 35.7, -114.0, 34.3, -113.1; 32.9, -113.5; 32.2, -113.6; 31.7, -114.5, 31.5, -117.1; 31.9, -117.9; 32.8, -118.4; 33.7, -121.0, 34.2, -121.6; 37.7, -123.8; 40.2, -125.4; 40.5, -125.4; 43.0, -125.2
Northern California	38.507, -123.222; 40.232, -124.583; 41.862, -124.598; 41.851, -122.276; 40.952, -122.276; 40.188, -121.536; 39.060, -121.196; 38.703, -122.246; 38.668, -123.104; 38.507, -123.222
San Francisco	36.890, -121.148; 36.546, -121.422; 36.535, -122.099; 38.489, -123.207; 38.652, -123.090; 38.692, -122.243; 38.987, -121.344; 38.376, -121.005; 37.503, -121.461; 36.859, -121.135; 36.890, -121.148
Central Coast	34.406, -119.970; 34.320, -121.127; 36.519, -122.091; 36.547, -121.425; 36.828, -121.110; 36.814, -120.724; 36.463, -120.636; 35.982, -120.111; 35.212, -119.848; 34.378, -119.970; 34.406, -119.970
Los Angeles	33.043, -116.303; 32.498, -117.104; 33.577, -117.971; 33.649, -118.429; 33.973, -118.658; 34.328, -119.974; 34.619, -119.974; 34.557, -117.132; 33.043, -116.303
Mojave	33.022, -114.677; 33.073, -116.287; 34.551, -117.131; 34.627, -119.952; 35.193, -119.860; 35.230, -118.633; 36.313, -118.572; 36.436, -117.652; 33.022, -114.677
Mid	35.220, -119.839; 35.988, -120.085; 36.485, -120.619; 37.044, -120.619; 37.241, -119.223; 37.794, -118.565; 37.665, -117.703; 36.452, -117.662; 36.320, -118.606; 35.253, -118.647; 35.220, -119.839
Northeast	40.544, -120.410; 43.0, -121.984; 43.0 -119.011; 40.721, -119.011; 40.544, -120.410

Table L2. Completeness magnitudes for the northern California region, California.

Starting year	Ending year	Magnitude of completeness
1850	1855	7.3
1855	1860	7.1
1860	1865	6.7
1865	1875	6.4
1875	1880	6.3
1880	1890	6.2
1890	1932	6.1
1932	1942	5.6
1942	1952	5.2
1952	1957	5.1
1957	1997	4.7
1997	2007	3.4

Table L3. Completeness magnitudes for the San Francisco region, California.

Starting year	Ending year	Magnitude of completeness
1850	1855	6.0
1855	1860	5.8
1860	1870	5.7
1870	1885	5.6
1885	1895	5.5
1895	1932	5.3
1932	1942	4.5
1942	1967	4.1
1967	1997	4.0
1997	2000	2.6
2000	2007	2.4

Table L4. Completeness magnitudes for the Central Coast region, California.

Starting year	Ending year	Magnitude of completeness
1850	1855	7.4
1855	1860	7.3
1860	1870	6.6
1870	1890	6.5
1890	1905	6.4
1905	1932	6.3
1932	1987	4.1
1987	1992	3.8
1992	1997	3.5
1997	2000	2.9
2000	2007	2.7

Table L5. Completeness magnitudes for the Los Angeles region, California.

Starting year	Ending year	Magnitude of completeness
1850	1855	6.9
1855	1870	6.4
1870	1875	6.2
1875	1890	6.0
1890	1905	5.8
1905	1932	5.7
1932	1993	3.9
1993	1997	2.8
1997	2000	2.6
2000	2007	2.1

Table L6. Completeness magnitudes for the Mojave region, California.

Starting year	Ending year	Magnitude of completeness
1850	1855	8.0
1855	1865	7.4
1865	1870	7.3
1870	1875	7.1
1875	1880	7.0
1880	1890	6.9
1890	1895	6.8
1895	1910	6.7
1910	1932	6.6
1932	1993	4.1
1993	1997	3.0
1997	2000	2.9
2000	2007	2.2

Table L7. Completeness magnitudes for the Mid region, California.

Starting year	Ending year	Magnitude of completeness
1850	1855	8.0
1855	1865	7.5
1865	1870	6.6
1870	1875	6.5
1875	1880	6.3
1880	1890	6.2
1890	1932	6.1
1932	1957	4.2
1957	1992	3.9
1992	1997	3.4
1997	2000	3.2
2000	2007	2.7

Table L8. Completeness magnitudes for the Northeast region, California.

Starting year	Ending year	Magnitude of completeness
1850	1932	8.0
1932	1942	5.7
1942	1967	5.3
1967	1997	4.7
1997	2007	3.7

Table L9. Completeness magnitudes for the rest of California.

Starting year	Ending year	Magnitude of completeness
1850	1865	8.0
1865	1870	7.4
1870	1885	7.2
1885	1910	7.1
1910	1932	6.9
1932	1942	6.0
1942	1957	5.6
1957	1997	5.1
1997	2007	4.0

Table L10. Calculation of the mean rate of $M\geq5$ earthquakes/year for 1850–2011, California. Confidence bounds are from the stationary Poissonian.

[Values include corrections for rounding and magnitude errors]

Data	Preferred rate	Lower bound	Upper bound
Whole State, b=1	7.9	3.1	25.4
Whole State, b=0.98	7.6	3.1	23.8
Whole State, b=1.02	8.2	3.1	27.2
NoCal, b=1	4.2	1.4	15.2
NoCal, b=0.98	4.1	1.4	14.1
NoCal, b=1.02	4.4	1.4	16.3
SoCal, b=1	3.7	1.5	10.8
SoCal, b=0.98	3.5	1.6	10.2
SoCal, b=1.02	3.8	1.5	11.4

Table L11. Magnitude-averaged seismicity rates, expressed in terms of M≥5 earthquakes/year for 1984–2011, California

[Rounding-and magnitude-error corrections applied. Confidence bounds given are from the stationary Poissonian function]

Data	Preferred rate	Lower bound	Upper bound
Whole State, b=1	5.8	4.9	7.2
Whole State, b=0.98	6.1	5.2	7.5
Whole State, b=1.02	5.6	4.7	6.9
NoCal, b=1	2.2	1.6	3.0
NoCal, b=0.98	2.65	2	3.6
NoCal, b=1.02	2.3	1.7	3.1
SoCal, b=1	3.7	3.2	4.5
SoCal, b=0.98	3.9	3.3	4.7
SoCal, b=1.02	3.5	3.0	4.3

Table L12. Direct-count earthquake rates for whole State of California, 1932–2011.

[Rates are incremental and are given in earthquakes per year. No corrections for rounding or magnitude error.]

Magnitude	Rate	Poisson Confidence Interval	Poisson plus global analog confidence interval
4.5–5.0	12.8	12–13.5	12–17.9
5.0–5.5	4.0	3.6–4.4	3.6–5.5
5.5–6.0	1.4	1.1–1.6	1.1–1.7
6.0–6.5	0.45	0.36–0.59	0.36–0.59
6.5–7.0	0.2	0.12–0.32	0.12–0.32
7.0–7.5	0.0625	0.025–0.148	0.025–0.148
7.5–8.0	0.0125	0.013–0.0688	0.013–0.0688

Table L13. Direct-count earthquake rates for southern California region, 1932–2011.

[Rates are incremental and are given in earthquakes per year]

Magnitude	Rate	Poisson confidence interval	Global analog confidence interval
4.5–5.0	7.7	7.2–8.3	7.2–10.4
5.0–5.5	2.3	1.9–2.6	1.9–3.2
5.5–6.0	0.7	0.6–0.86	0.6–1.0
6.0–6.5	0.23	0.14–0.34	0.14–0.34
6.5–7.0	0.13	0.06–0.23	0.06–0.23
7.0–7.5	0.04	0.01–0.11	0.01–0.11
7.5–8.0	0.013	0.0013–0.069	0.0013–0.069

Table L14. Direct-count earthquake rates for northern California region, 1932–2011.

[Rates are incremental and are given in earthquakes per year]

Magnitude	Rate	Poisson confidence interval	Global analog confidence interval
4.5–5.0	5.1	4.6–5.6	4.6–8.5
5.0–5.5	1.7	1.4–2.0	1.4–2.7
5.5–6.0	0.64	0.48–0.82	0.48–0.82
6.0–6.5	0.23	0.14–0.34	0.14–0.34
6.5–7.0	0.08	0.03–0.16	0.03–0.16
7.0–7.5	0.03	0.005–0.09	0.005–0.09
7.5–8.0	--	--	--

Table L15. Direct-count earthquake rates, San Francisco Bay Area subregion, California, 1932-2011.

[Rates are incremental and given in earthquakes per year]

Magnitude	Rate	Poisson confidence interval	Global analog confidence interval
4.5–5.0	0.89	0.7–1.07	0.7–1.07
5.0–5.5	0.24	0.17–0.36	0.17–0.36
5.5–6.0	0.1	0.05–0.19	0.05–0.19
6.0–6.5	0.013	0.0013–0.07	0.0013–0.07
6.5–7.0	0.013	0.0013–0.07	0.0013–0.07
7.0–7.5	--	--	
7.5–8.0	--	--	

Table L16. Direct-count earthquake rates, Los Angeles subregion, California,1932–2011.

[Rates are incremental and are given in earthquakes per year]

Magnitude	Rate	Poisson confidence interval	Global analog confidence interval
4.5–5.0	1.5	1.2–1.8	1.2–1.9
5.0–5.5	0.4	0.29–0.58	0.29–0.59
5.5–6.0	0.11	0.06–0.20	0.06–0.2
6.0–6.5	0.03	0.005–0.09	0.005–0.09
6.5–7.0	0.04	0.011–0.11	0.011–0.11
7.0–7.5	--	--	
7.5–8.0	0.013	0.0013–0.07	0.0013–0.07

All confidence limits given in the tables L18–L17 are two-tailed 95-percent confidence estimates, meaning that 95 percent of the entire data set is within the confidence interval. Earthquake rates represent where earthquakes nucleated, not where they propagated. The 1857 Ft. Tejon earthquake, for example, is recorded as a northern California event because its epicenter in the source catalog is just north of the northern/southern California boundary. This increases the pre-instrumental seismicity rate in northern California.

The average annual seismic moment release rate is calculated directly from the catalog. In this calculation all cataloged earthquakes are used, without correcting for catalog completeness, because the moment is dominated by the largest earthquakes and, hence, is not as sensitive to the completeness of the smaller events. Using catalog data from 1850–2011 results in 2.29×10^{19} Nm seismic moment/year. Keeping in mind that the 1769–1850 portion of the catalog is uncertain, going back to the beginning of the California Mission period results in 1.71×10^{19} Nm of seismic moment/year. Using only the instrumental post-1932 period from the catalog results in 1.28×10^{19} Nm of seismic moment/year.

All of the seismicity rates given above are for the full earthquake catalog. Traditionally, the declustered earthquake catalog (aftershocks and foreshocks removed) has been used for some applications. The National Seismic Hazard Maps use the Gardner and Knopoff (1974) routine for declustering. Using this routine on the catalog results in the following fraction of earthquakes being removed from the catalog, as a function of magnitude (table L17). Note that identification as an aftershock or foreshock is magnitude-dependent (Gardner and Knopoff,1974) because the routine indentifies the largest earthquake in a sequence as the mainshock. An alternative is to identify the first earthquake in a triggering sequence as the mainshock and any earthquake that is triggered as an aftershock; in this case aftershocks are observed to follow the same (normalized) magnitude-frequency statistics as other earthquakes (Felzer*,* 2004).

Table L17. Fraction of Uniform California Earthquake Rupture Forecast, Version 3 catalog earthquakes in California defined as aftershocks or foreshocks by the Gardner and Knopoff (1974) routine.

Magnitude range	Percentage of earthquakes defined as foreshocks or aftershocks
$4.0 \le M < 4.5$	65
$4.5 \le M < 5.0$	60
$5.0 \le M < 5.5$	47
$5.5 \le M < 6.0$	62
$6.0 \le M < 6.5$	18
$6.5 \le M < 7.0$	17
$7.0 \le M < 7.5$	0

To provide perspective on the accuracy of the 1850–2011 mean rate, the rates measured for different starting years are given in table L18. For measurements starting after 1870, the rates are between 5 and 8 $M \ge 5$/year. Given that California has not experienced any earthquakes $M > 7.5$ since 1910, it is likely that most of the measured rates in table L18 are below the true long-term average.

Table L18. Magnitude-averaged seismicity rates for California earthquake in different starting years.

Time period	Mean rate of $M \ge 5$ earthquakes (magnitude-averaged seismicity rates)
1870–2011	7.1
1885–2011	7.0
1942–2011	5.7
1984–2011	5.8
1990–2011	5.7

References

Biasi, G.P., Weldon, R. J., II, 2009, San Andreas fault rupture scenarios from multiple paleoseismic records—Stringing pearls: Bulletin of the Seismological Society of America, v. 99, p. 471–498.

Bird, P., Kagan Y.Y., 2004, Plate-tectonic analysis of shallow seismicity—Apparent boundary width, beta, corner magnitude, coupled lithosphere thickness, and coupling in seven tectonic settings: Bulletin of the Seismological Society of America, v. 94, p. 2380–2399.

Buffe, C.G., and Varnes, D.J., 1993, Predictive modeling of the seismic cycle of the greater San Francisco Bay region: Journal of Geophysical Research*,* v. 98, p. 9871–9883.

Burroughs, S.M., Tebbens S.F., 2002, The upper-truncated power law applied to earthquake cumulative frequency-magnitude distributions—Evidence for a time-independent scaling parameter: Bulletin of the Seismological Society of America, v. 92, p. 2983–2993.

Felzer, K.R., 2006, Calculating the Gutenberg-Richter *b* value [abs.]: Eos (American Geophysical Union Transactions), v. 87, Fall meeting supplement, abs. S42C-08.

Felzer, K.R., 2008, Calculating California seismicity rates, appendix I *of* 2007 Working Group on California Earthquake Probabilities, The uniform California earthquake rupture forecast, version 2 (UCERF 2), U. S. Geological Survey Open-File Report 2007–1437I.

Felzer, K.R., Abercrombie, R.E., Ekstrom, G., 2004, A common origin for aftershocks, foreshocks, and multiplets: Bulletin of the Seismological Society of America, v. 94, p. 88–98.

Gardner, J.K., Knopoff, L., 1974, Is the sequence of earthquakes in southern California, with aftershocks removed, Poissonian?: Bulletin of the Seismological Society of America., v. 64, p. 1363–1367.

Gutenberg, B., Richter, C.F., 1944, Frequency of earthquakes in California: Bulletin of the Seismological Society of America, v. 4, p. 185–188.

Hutton, K.L., Woessner, J., Hauksson, E., 2010, Earthquake monitoring in southern California for seventy-seven years: Bulletin of the Seismological Society of America., v. 100, p. 423–446.

Weichert, D.H., 1980, Estimation of the earthquake recurrence parameters for unequal observation periods for different magnitudes: Bulletin of the Seismological Society of America., v. 70, p. 1337–1346.