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Evaluation of 2002 USGS National Seismic Hazard Assessment
Final Report

National Seismic Hazard Mapping Project
U.S. Geological Survey

Introduction

We have developed and tested a new set of seismic hazard and deaggregation computer programs and applied them to the 29 sites of RG 1.165. The primary code uses a Monte Carlo method to sample through a series of logic trees that vary key parameters in the hazard calculation. This master code calls the hazard calculation codes that were used to make the 2002 USGS national seismic hazard maps. The new codes provide the mean seismic hazard curve and seismic hazard curves of selected fractiles, such as 15th, 50th, and 85th. Two other new codes we have developed for this project deaggregate the results in two forms. One code deaggregates the overall mean or median hazard curves. The other code finds the median value in each magnitude-distance bin as specified in the procedure in RG 1.165.

In the following report, we describe the logic trees used in the new procedure and show plots of the results. The logic trees are an expansion of those used in the 2002 national seismic hazard maps. We wanted to make sure that the added logic nodes did not substantially bias the mean hazard curves derived from the Monte Carlo runs relative to the mean hazard curves derived from the more limited logic trees used for the national maps. We also wanted the logic trees to produce an estimate of the uncertainties that was larger for regions that have had little historic seismicity but may have the potential for producing significant earthquakes, such as the Gulf Coast and the upper Midwest. These requirements led to extensive testing of alternative logic trees during the course of this project.

Description of Logic Trees

Figures 1-3 show the logic trees used in the final calculations. For all sources, we used a logic tree of attenuaiton relations, with weighting identical to that used in the 2002 national maps. For the New Madrid source (Fig. 1) we used logic trees on characteristic magnitude, location of pseudofaults, recurrence time, and pseudofault endpoints. The first three of these are identical to those used in the 2002 maps. The recurrence time is characterized by a log-normal distribution with a variability determined from an analysis of the observed times of past large New Madrid earthquakes (1811-12, about 1450, and 900 A.D.). The logic tree on characteristic magnitude ranges from M7.3 to M8.0, essentially encompassing the range of magnitudes determined for the largest 1811-12 event by analyses of the isoseismal data by various investigators.

The logic tree for the Charleston, South Carolina source is depicted in Figure 2. The two areal source zones are specified in the node "1886 rupture model." These are the same areal zones used in the 2002 maps. The recurrence interval is specified as a log-

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normal distribution, with the same variability as that determined for New Madrid. The logic tree for the characteristic magnitude is the same as that used in the 2002 maps.

The logic tree for the spatially-smoothed seismicity required the most analysis for this work. To quantify the variability of the seismicity rate from the catalog, we re-sampled the catalog for each run. Originally we had also considered magnitude variability by re-assigning the magnitudes. However, we found that this biased the hazard lwo in areas dominated by the background source zones. Since the a-value for these zones were determined from the rates of magnitude 3.0 and above, varying the magnitudes preferentially reduced the rates, since our original catalog did not include events below magnitude 3.0. Thus the mean rate was underestimated from the re-assigned magnitudes. We removed the magnitude re-assignment from the code. Another question arose about varying the locations of the earthquakes in the catalog, after re-sampling. We found that this tended to reduce the hazard in areas with spatial clusters of earthquakes. We think that these clusters are real and their effects should not be diluted by varying the epicentral locations. Furthermore, the spatial smoothing tends to account for uncertainties in earthquake locations. Therefore, we did not vary the locations in the catalog.

The logic tree included a node for varying the Mmax used for the extended margin and craton Mmax zones. This Mmax is applied to all calculations involving the historic seismicity. We decided on using +- 0.2 magnitude units for the variation in the mbMax. We wanted a symmetrical variation so as not to introduce bias with respect to the 2002 values, but we did not want to use unrealistically large values of Mmax.

The key to the logic tree for the smoothed seismicity is the node for seismicity model. The 2002 maps use four models to capture the epistemic uncertainty. These models are: 1) M >=3.0 since 1924, 2) M>= 4.0 since 1860, 3) M>=5.0 since 1700, and 4) background zones. In particular, we felt that the occurrence of magnitude 5 and above earthquakes provided an important guide to where we might expect future moderate or large earthquakes. The separation of the seismicity into three models based on a minimum magnitude was designed to give the occurrence of larger events more importance in the hazard assessment. Using one model with a maximum likelihood method would treat the M4 and M5 events the same as the M3 events for the a-value estimation, although they would influence the b-value calculation. We did not vary the regional b-value of 0.95 used in the calculations, which is the same as that used in the 2002 maps (for Charlevoix area we used b of 0.76). We found that the catalog resampling provided reasonable variations in seismicity rates of moderate earthquakes, without the need for varying the regional b-value.

The 2002 maps employed adaptive weighting of the four seismicity models. This procedure was implemented so as not to lower the hazard in high seismicity areas by including the background zones. For each cell used in the seismicity-rate grid, the historic seismicity rate was compared to that of the background zone. The historic seismicity rate was determined from the weighted average of the seismicity rates from models 1-3. When the historic seismicity rate exceeded the background zone rate, only the historic seismicity rate was used for that cell (weights of 0.5, 0.25, 0.25 for models 1-3, respectively). In that case, the background zone was not considered. When the background zone rate was higher than the historic-seismicity rate for that cell, then the background zone was included in the mean seismicity rate for that cell, such that the weights were 0.4, 0.2, 0.2, 0.2 for models 1-4, respectively. The problem with this adaptive weighting is that it slightly violates the observed total rate of M3+ earthquakes by about 11%. This adaptive weighting is also described in the documentation for the 1996 maps (Frankel et al., 1996).

It is problematic applying the adaptive weighting scheme to the Monte Carlo simulations. We want to have a uniform procedure applied to all sites. We do not want to apply a three-model draw for some sites and a four-model draw for others. Even this approach would not be the same as that used in the national maps, since the number of models used varied with different seismicity-rate cells. We concluded that it was better to sacrifice total consistency with the national hazard map procedure in order to quantify the epistemic uncertainty in a uniform manner for all sites. The results of this decision are described in the next section.

Note that the M5 model actually consists of 0.8 wt for M5's and 0.1 wt for M3 and 0.1 weight for M4 models. We included the other two models with low weights so that drawing the M5 model would not lower the hazard to near zero at sites at large distances from M5's but close to M3's and M4's. This point will be discussed later with respect to individual sites. Without including the M3 and M4 models, sites such as North Anna that are lacking in nearby M5+ earthquakes would have many runs with very low hazard values that, we think, bias the uncertainty distribution to very low values of hazard. Using a large smoothing distance of 150 km raises the lower fractiles generated by distinct M5 earthquakes, but still results in highly asymmetric distributions. The use of the M3 and M4 models with small weights when the M5 model is drawn reduces this asymmetry.

The remaining node of the logic tree for the smoothed seismicity is that for the mblg to moment magnitude (Mw) conversion. This conversion is used in three places. First is the conversion from mblg to Mw when the attenuation relations are evaluated, since most of them are in terms of Mw. The code integrates the hazard using a truncated Gutenberg-Richter distribution for the incremental rates using mblg, the magnitude assigned in the catalog. The second procedure that uses the Mw to mblg conversion is when mblgmax is determined from Mwmax, since the maximum magnitudes are specified in terms of Mw. Finally, the Mw is used to calculate fault lengths used in the randomly-oriented strikes of the finite faults used in the hazard calculation. As in the 2002 maps, this node consists of the conversion formulas from Boore and Atkinson (1987) and Johnston (1996).

Logic trees were also used for the Meers and Cheraw faults. The recurrence times and characteristic magnitudes were varied for these faults. The variability of recurrence time was the same as that used for the New Madrid source. For the Cheraw fault, there is a node with branches for the characteristic and truncated Gutenberg-Richter recurrence models, as was used for the national maps. These are given equal weights, as in the national maps.

Results at Selected Sites

For most sites the mean seismic hazard curves derived from the Monte Carlo method are very similar to those derived from the national map model. In most cases, the probabilistic ground motions derived from the Monte Carlo mean hazard curve are within 15% of those from the mean curves used in the national seismic hazard maps, for an annual probability of 1 x 10 $^{-5}$. For each site we used 200 runs to determine the mean, median, 15th and 85th percentile hazard curves. The hazard curves for the 200 runs were ranked at each ground motion level used in the calculations to determine the percentile hazard curves. We found that using greater than 200 runs did not significantly change the results.

Figure 4 shows the results for 10 Hz spectral acceleration (Sa) for Three Mile Island. This example shows very good agreement between the Monte Carlo mean curve and the mean from the national maps (Frankel et al, 2002). The median and mean curves from the Monte Carlo method are very similar in this case. In general the distribution of uncertainty is asymmetrical on a log probability log ground motion plot. That is, the ratio of the 50th/15th ground motions at 1 x 10 $^{-5}$ annual probability, for example, is much greater than the ratio of the 85th/50th ground motions at that probability. After some testing, we concluded that this asymmetry is largely caused by the M5+ seismicity model. In areas lacking magnitude 5 earthquakes in the catalog, the M5 models will produce very low hazard. This trend was mitigated by the large smoothing distances of 150 km used in some of the models and in the use of the M3 and M4 models with small weights in the draw for the M5 model.

The 1 Hz hazard curves (Figure 5) for Three Mile Island show a larger uncertainty than the 10 Hz curves. This is largely due to the greater epistemic uncertainty in the attneuaiton relations at 1 Hz compared to 10 Hz. The use of the double-corner model of Atkinson and Boore (1995) increase the epistemic uncertainty at 1 Hz. The Monte Carlo mean curve is slightly lower than that of the 2002 maps. We found that this is often true for sites in areas with significant historic seismicity. Part of this is due to the inclusion of the background zone in the Monte Carlo simulation as opposed to the adaptive weighting that does not use the background zone for the national maps for cells with substantial historic seismicity. At 1 Hz, the median curve in Figure 6 is significantly below the mean curve.

Figure 6 depicts the hazard curves for the South Texas site, an area removed from significant historic seismicity where the background zone hazard dominates. In this example the mean hazard curve from the Monte Carlo method is slightly higher than that from the 2002 maps. We found that this is generally true for sites where the background zones dominate. This is likely caused by the M3,4,5 models that had large smoothing distances and therefore, contribute to the hazard even at sites far from the epicenters.

The large uncertainty for the Texas site, compared to that at Three Mile Island, is largely caused by the contrast between the hazard from the background zone and the historic seismicity near the site. This contrast is greater for South Texas, since it is distant from clusters of historic earthquakes.

The hazard curves at Watts Bar for 10 Hz S.A. (Figure 7) show trends common to sites near seismically-active areas, in this case the eastern Tennessee seismic zone. The Monte Carlo mean is somewhat below the 2002 map mean, largely because of the inclusion of the background zone in the Monte Carlo mean. The median hazard curve is very similar to the mean hazard curve, as with Three Mile Island. The hazard curve uncertainty is again asymmetric with the larger uncertainty occurring for fractiles less than the median.

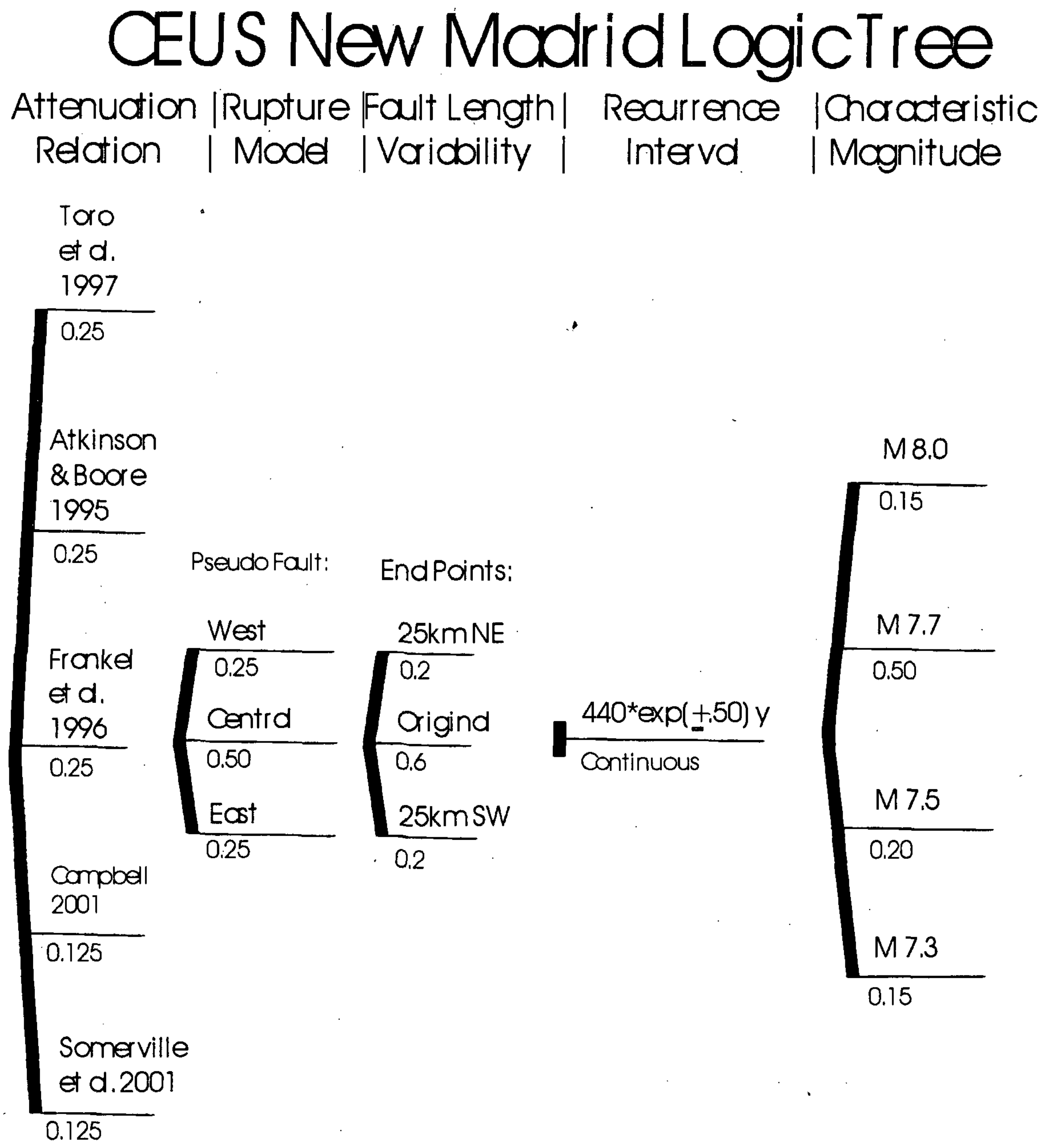


Figure 1. Logic tree used for New Madrid characteristic sources.

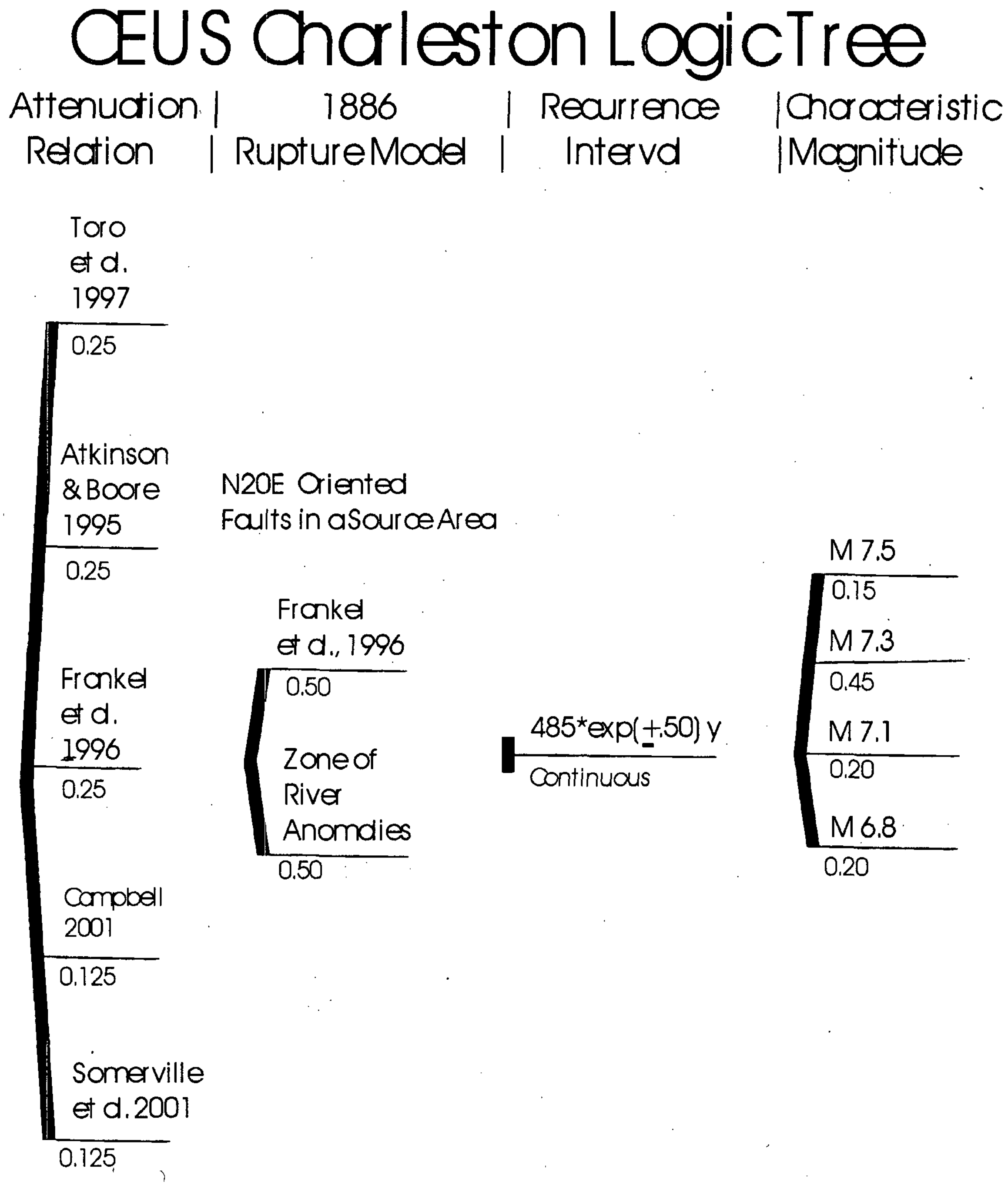


Figure 2. Logic tree used for Charleston, SC characteristic source.

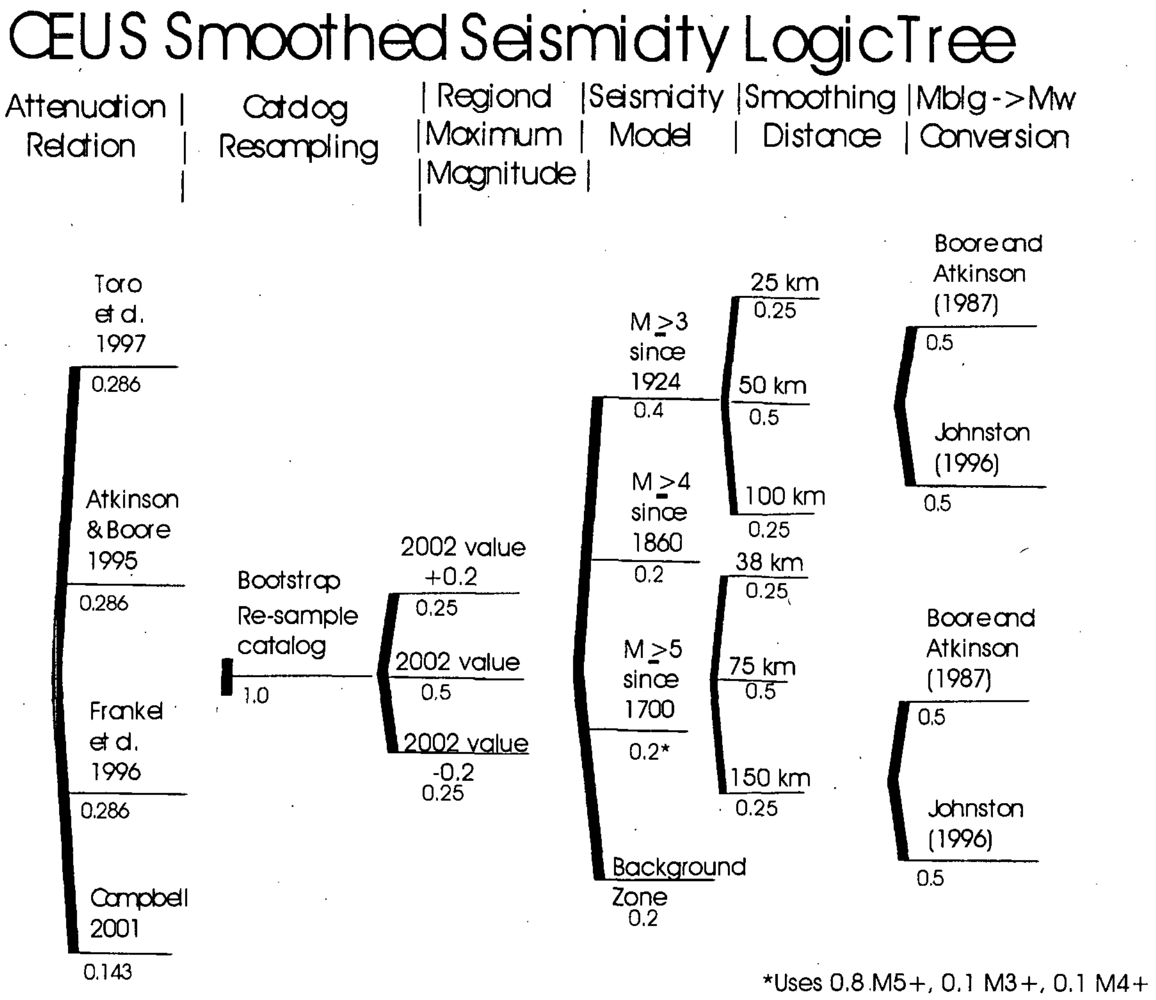
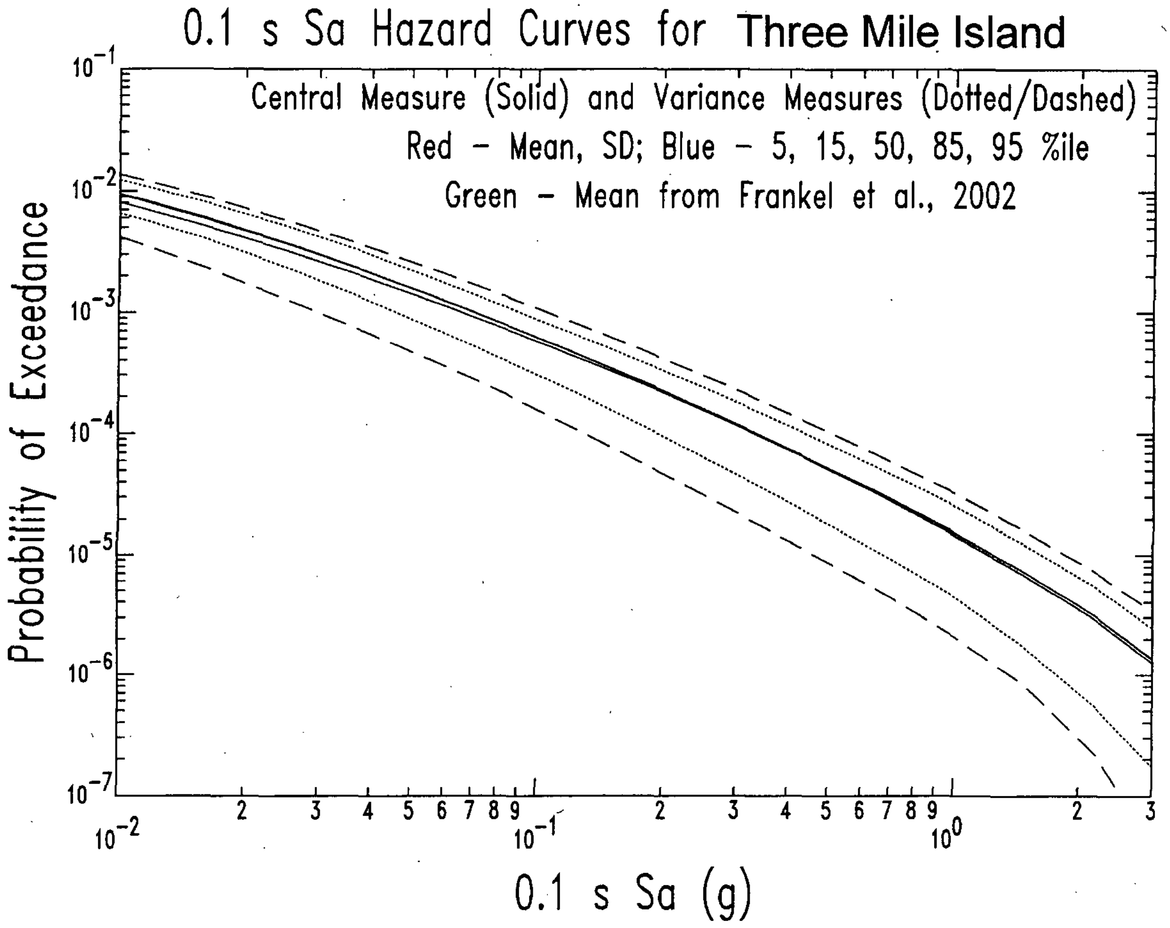
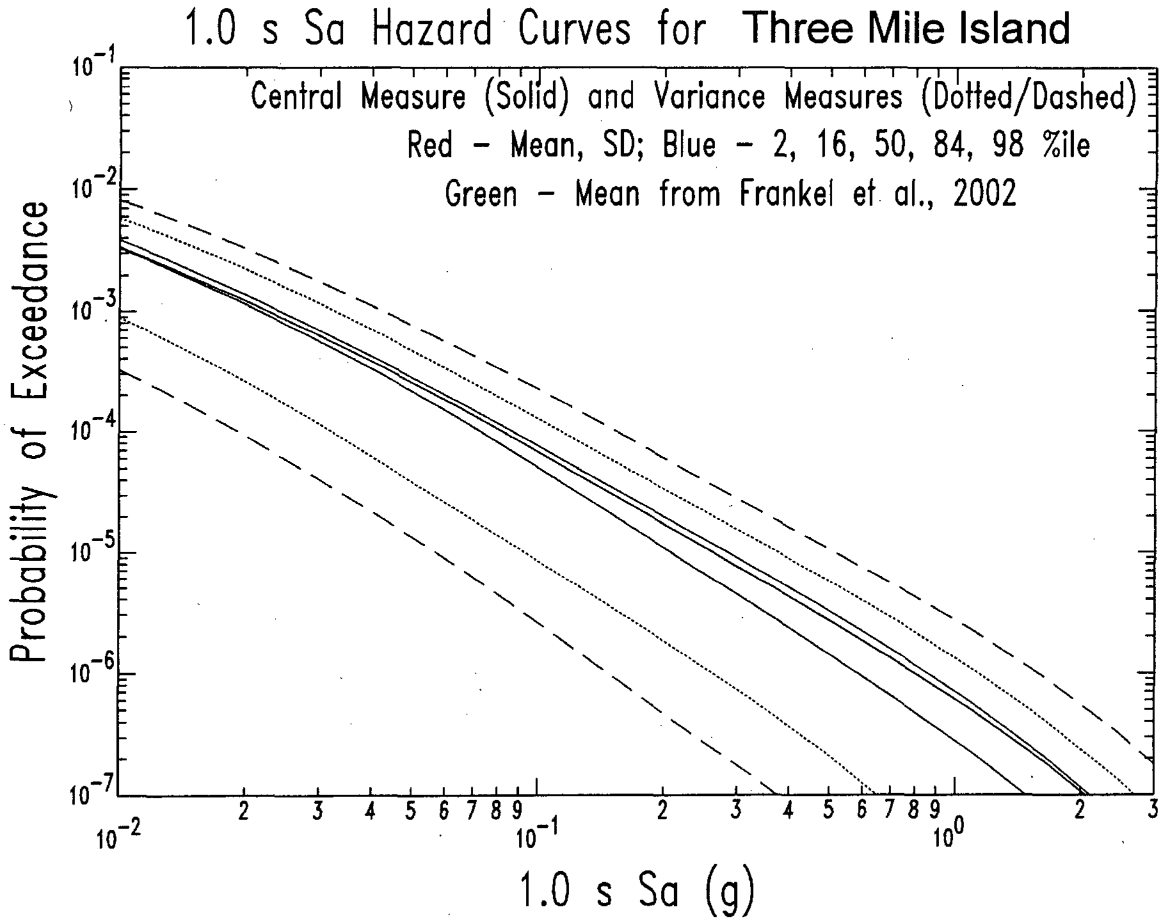
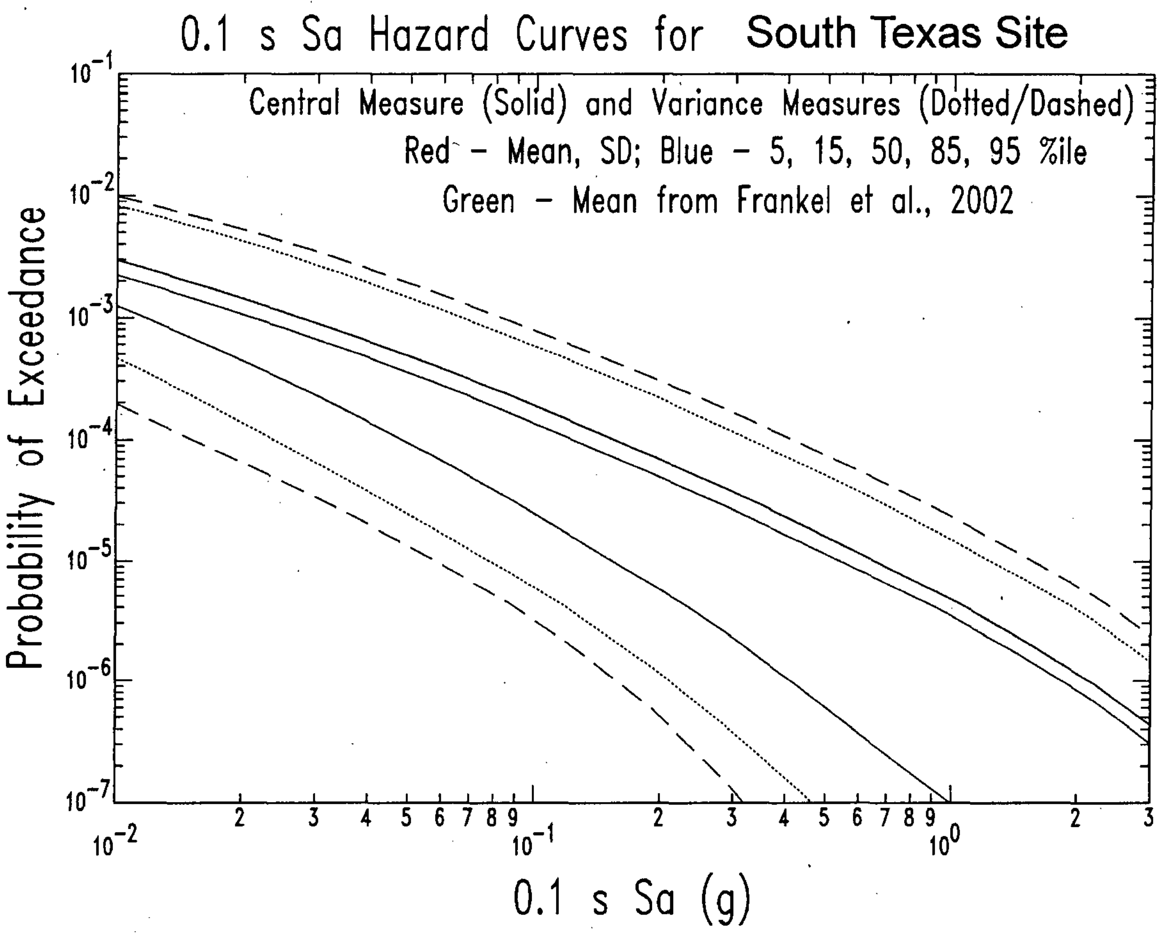


Figure 3. Logic tree used for spatially-smoothed seismicity.


0.1 s Sa Hazard Curves for Three Mile Island
Central Measure (Solid) and Variance Measures (Dotted/Dashed)
Red - Mean, SD; Blue - 5, 15, 50, 85, 95 %ile
Green - Mean from Frankel et al., 2002
Probability of Exceedance
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-2}
2
3
4
5
6
7
8
9
10^{-1}
2
3
4
5
6
7
8
9
10^{0}
2
3
0.1 s Sa (g)


1.0 s Sa Hazard Curves for Three Mile Island
Central Measure (Solid) and Variance Measures (Dotted/Dashed)
Red - Mean, SD; Blue - 2, 16, 50, 84, 98 %ile
Green - Mean from Frankel et al., 2002
Probability of Exceedance
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-2}
2
3
4
5
6
7
8
9
10^{-1}
2
3
4
5
6
7
8
9
10^{0}
2
3
1.0 s Sa (g)


0.1 s Sa Hazard Curves for South Texas Site
Central Measure (Solid) and Variance Measures (Dotted/Dashed)
Red - Mean, SD; Blue - 5, 15, 50, 85, 95 %ile
Green - Mean from Frankel et al., 2002
Probability of Exceedance
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-2}
2
3
4
5
6
7
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9
10^{-1}
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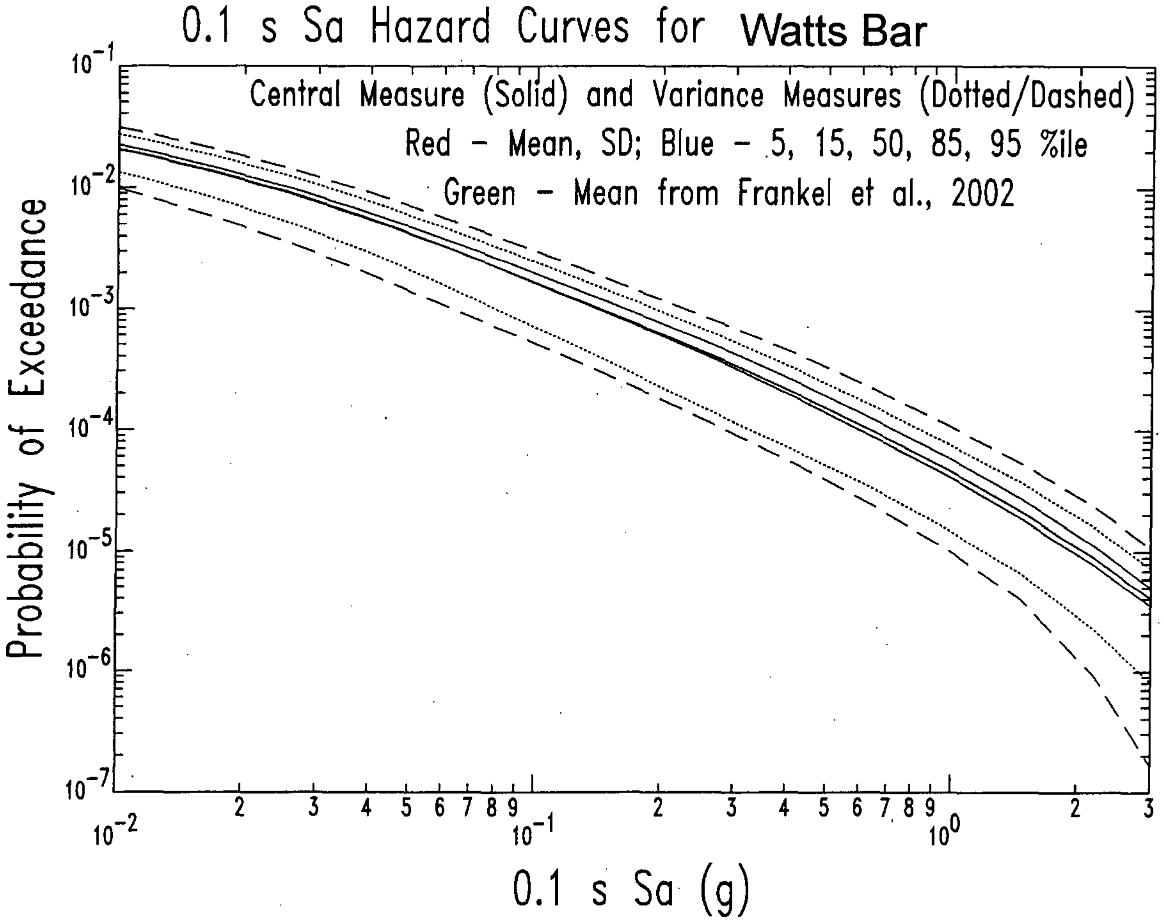
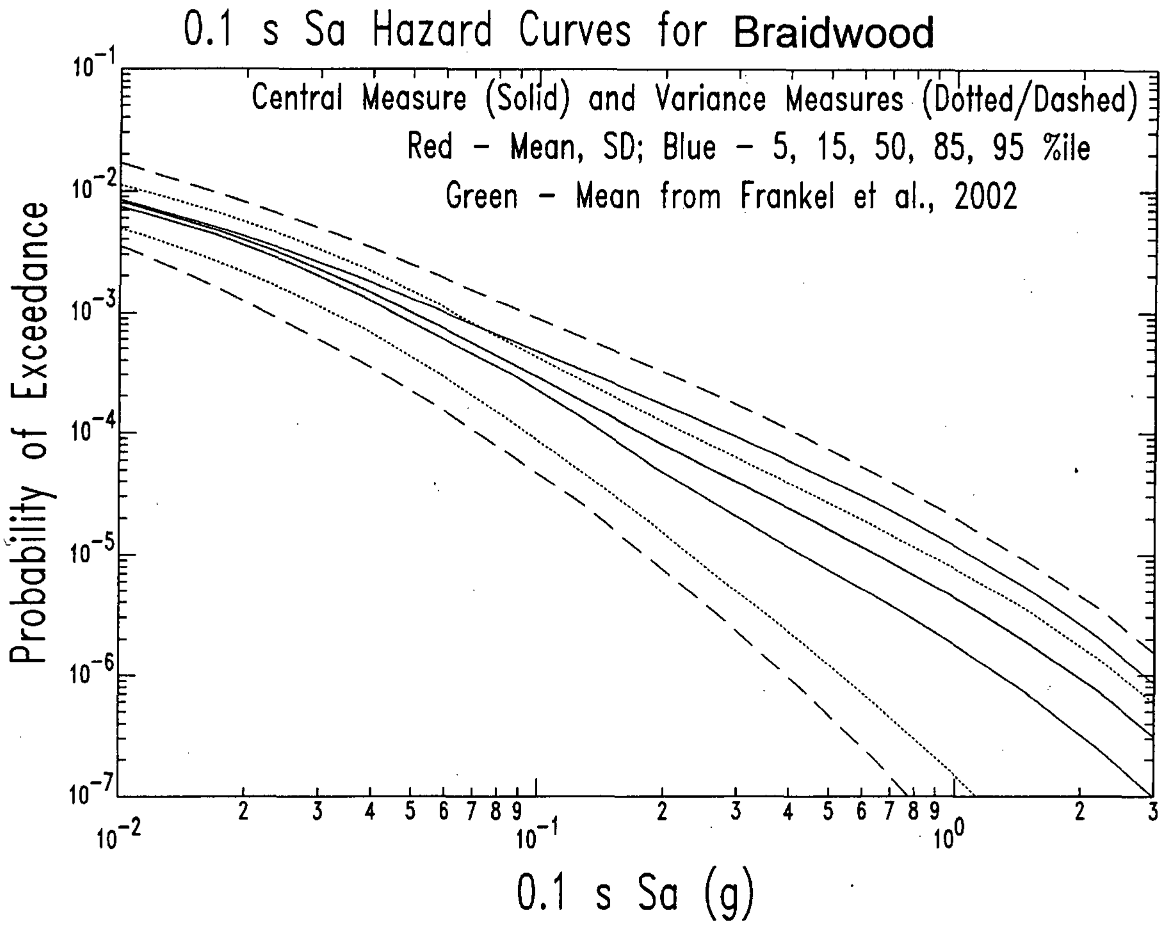
3
4
5
6
7
8
9
10^{0}
2
3
0.1 s Sa (g)


0.1 s Sa Hazard Curves for Watts Bar
Central Measure (Solid) and Variance Measures (Dotted/Dashed)
Red - Mean, SD; Blue - 5, 15, 50, 85, 95 %ile
Green - Mean from Frankel et al., 2002
Probability of Exceedance
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.1 s Sa (g)
10^{-2}
2
3
4
5
6
7
8
9
10^{-1}
2
3
4
5
6
7
8
9
10^{0}
2
3


0.1 s Sa Hazard Curves for Braidwood
Central Measure (Solid) and Variance Measures (Dotted/Dashed)
Red - Mean, SD; Blue - 5, 15, 50, 85, 95 %ile
Green - Mean from Frankel et al., 2002
Probability of Exceedance
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.1 s Sa (g)
10^{-2}
2
3
4
5
6
7
8
9
10^{-1}
2
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9
10^{0}
2
3