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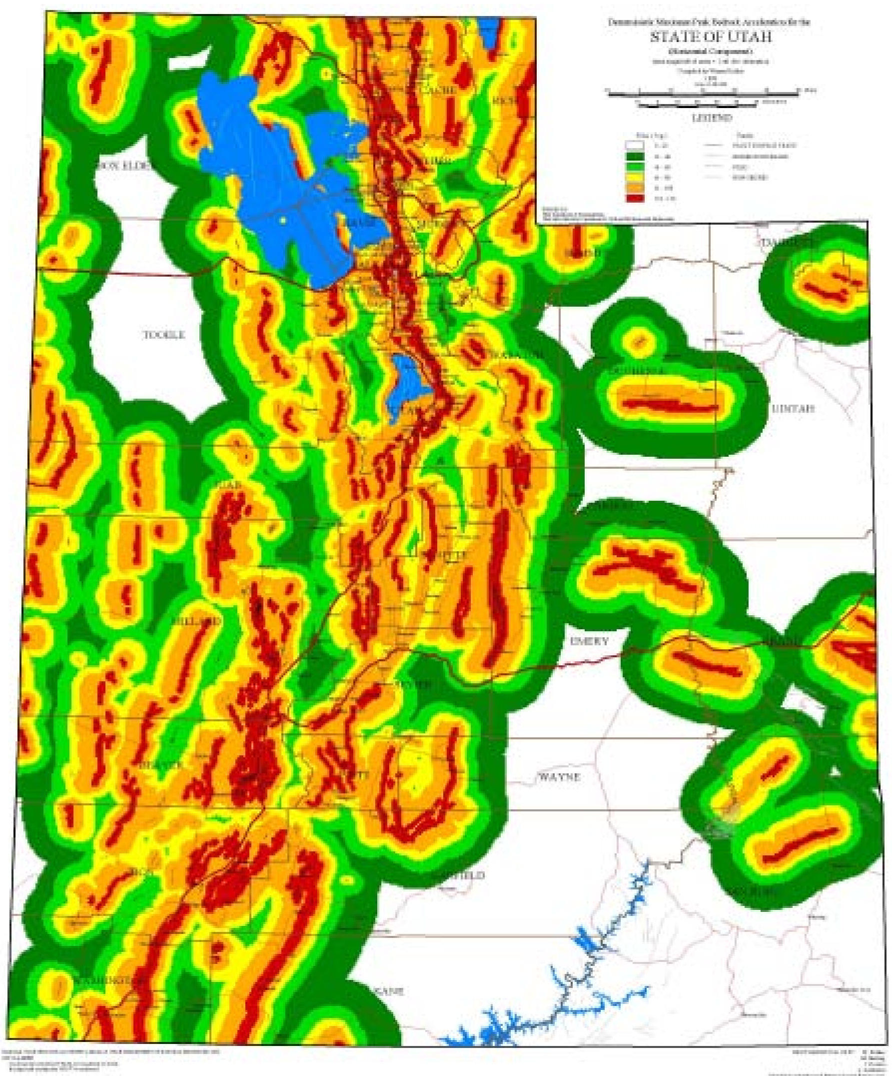

Miscellaneous Publication 02-11 **July 2002**
UTAH GEOLOGICAL SURVEY
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16. Abstract

Maps of deterministic maximum peak horizontal and vertical bedrock accelerations for Utah were prepared because probabilistic accelerations locally, in some instances, exceed deterministic values and slip-rate data on which probabilistic analyses are based typically is poor.

Quaternary faults and folds inside Utah and within 100 km of its border were considered to be earthquake sources. Maximum magnitudes were assigned based on fault type and rupture length. Three attenuation relationships were used to calculate mean and 84^{th} percentile peak horizontal and vertical bedrock accelerations at points on a one-km grid. Contours of peak horizontal and vertical bedrock acceleration were interpolated from the grid values. Earthquake sources and calculated acceleration data were managed and displayed using ArcView GIS and its' Spatial Analyst extension. The model can be run on the entire Fault theme (overnight), or on a subset (such as proximity to interstates), based on standard spatial queries available within ArcView.

17. Key Words **deterministic bedrock acceleration, GIS, Quaternary faults**	**18. Distribution Statement: No Restrictions**

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EXECUTIVE SUMMARY

Maximum ground motion maps for the State of Utah were prepared for the Utah Department of Transportation to provide context for probabilistic ground motion maps. Deterministic procedures were used to prepare maps of both horizontal and vertical maximum peak bedrock acceleration.

Spatial data on Quaternary faults and folds inside Utah and within 100 km of Utah's border were collected from available sources. Where fault dip was uncertain, ground motion was modeled with the faults dipping both directions. Mean and 84th percentile Maximum Considered Earthquake (MCE) magnitudes were assigned to each fault based on fault rupture length and slip type using the relationships by Wells and Coppersmith (1994). Spatial earthquake-source data were managed and displayed using ArcView GIS.

Three recently developed ground motion attenuation relationships were considered, one of which is specific to extensional tectonic regimes, such as that found in Utah, and the others for comparison purposes. Mean and 84th percentile peak horizontal and vertical bedrock accelerations were calculated for the entire state for mean MCE magnitudes at points on a 1-km grid. The 1-km grid acceleration calculations were made with the Spatial Analyst extension to ArcView GIS. Contours of peak horizontal and vertical bedrock acceleration were interpolated from the grid values to prepare the maps.

The need for the deterministic ground motion map was based on observations that probabilistic values in some locations exceed deterministic values, and slip-rate data needed for probabilistic analyses typically are poor for Utah faults. The deterministic maps produced by this research provide the first systematic assessment of maximum peak bedrock accelerations for the State of Utah. Future research building on these maps could be maps of maximum bedrock spectral accelerations for selected fundamental periods, as well as the incorporation of soil or site effects where that information is available.

The authors recommend the use of the Abrahamson and Silva relationship, utilizing the “mean” magnitude and the “mean plus sigma” attenuation as an upper bound on the expected bedrock motions in the state. Utilizing the included CD, a reader can investigate the effects of using the other relationships.

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INTRODUCTION

In ancient times, the Chinese constructed earthquake detectors by placing small marbles in the mouths of dragons carved from stone. When earthquakes occurred, even very small amounts of ground shaking would cause the marble to fall from the mouth of the dragon. Thus, even low-magnitude earthquakes could be detected. Seismic events have been recorded throughout the world for nearly three thousand years, showing that throughout history, people were aware that certain areas are prone to earthquakes.

Beginning in the early 1900s, instrumentation has recorded seismic events with increasing accuracy. The information gathered from these instruments has helped geologists, seismologists, and other scientists to better understand the causes of earthquakes and the forces they generate.

Many of today's large metropolitan areas are found on or near very active seismic areas, putting many people at great risk. Of particular concern is the failure of buildings and urban infrastructure. Recent seismic events, such as the 1994 Northridge, 1989 Loma Prieta, 1985 Mexico City, and 1995 Kobe earthquakes, have shown how single events can reek havoc on cities. Buildings, bridges, and other structures are leveled or damaged beyond repair. Even more devastating is the loss of countless lives. It is evident much is still to be learned about seismic motion and how best to design structures to resist such motion.

LITERATURE REVIEW

Since 1948, seismic hazard maps of the United States have been produced. Aiding in the design of structures, different sources have created various maps that help predict the seismic hazard for a particular area. One map extensively used as a design requirement is the *Seismic Zone Map of the United States* from the Uniform Building Code (ICBO, 1997), shown in Figure 1. The map coarsely divides the United States into six distinct seismic zones numbered 0, 1, 2a, 2b, 3, and 4. These numbers represent various degrees of seismic risk and are used in the Uniform Building Code (UBC) to determine seismic base shear forces that structures must be designed to resist.

The National Earthquake Hazards Reduction Program (NEHRP), jointly sponsored by the Federal Emergency Management Agency (FEMA), the United States Geological Survey (USGS), and the National Science Foundation (NSF), produces the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (NEHRP, 1997). The preface of the 1997 Edition NEHRP Commentary states:

> The goal of the NEHRP Recommended Provisions is to present criteria for the design and construction of new structures subject to earthquake ground motions in order to minimize the hazard to life for all structures, to increase the expected performance of structures having a substantial public hazard due to occupancy or use as compared to ordinary structures, and to improve the capability of essential facilities to function after an earthquake. (NEHRP, Commentary, 1997, p. 2)

The Introduction and Acknowledgments section states: "The new design procedure is based on recently revised USGS spectral response maps. The design procedure involves new design maps based on the USGS hazard maps and a process specified within the body of the *Provisions*" (NEHRP, Provisions, 1997, p. v). The USGS produced their newest set of probabilistic hazard maps (used by

NEHRP) based on the most current data available (Frankel et al., 1996). Maps coupling peak accelerations or velocities with a probability of exceedance and with uncertainties in ground motion predictions are referred to as probabilistic maps. The efforts of the USGS are called the *National Seismic Hazard Mapping Project*.

The purpose of the nationwide project is to provide current and more detailed information about ground shaking hazards. Beyond producing probabilistic maps of peak accelerations and peak velocities, the project also includes probabilistic maps of spectral response for periods of 0.2, 0.3, and 1.0 seconds. Only major faults having potential to produce significant ground shaking and reliable slip rate data were included in the National Seismic Hazard Mapping Project. Figure 2 shows one such map produced by the USGS (Frankel et al., 1996). More detailed information regarding the Project can be found on the World Wide Web at the following address: http://geohazards.cr.usgs.gov/eq/

The maps produced for the National Seismic Hazard Mapping Project are based on values computed on a 0.1 degree or a 0.05 degree grid. The grid spacing distance varies across the country from 10.0 km/0.1 degree of longitude and 11.0 km/0.1 degree of latitude in south Texas to 7.9 km/0.1 degree of longitude and 11.1 km/0.1 degree of latitude in north Maine. In California, Nevada, and part of Utah where the maps are based on values computed on a 0.05 degree grid, the spacing varies from 4.7 km/0.05 degree of longitude and 5.5 km/0.05 degree of latitude in the south to 4.1 km/0.05 degree of longitude and 5.6 km/0.05 degree of latitude in the north.

Large-magnitude yet infrequent seismic events are typical of Utah faults. Such events tend to introduce large uncertainties in the results. Poor slip rate data for Utah faults add to the uncertainties in the probabilistic results. Therefore, deterministic maps showing maximum peak accelerations, not coupled with a probability of occurrence, would greatly complement the existing probabilistic maps.

The deterministic maps described in this paper use peak acceleration as the index parameter for seismic hazard. Maps of spectral acceleration could be produced in the future and would add to the utility of the deterministic seismic hazard analysis. Bedrock site conditions were selected for computing the acceleration values so that the results could be compared to the recent NEHRP maps, which also use bedrock site conditions. Maps of peak and spectral acceleration on different typical site conditions (for example, UBC or NEHRP site class C or D) also could be produced in the future.

The deterministic peak bedrock acceleration maps described below were produced using Geographic Information System (GIS) technology that would allow the data files produced to be used for additional, more extensive, or more specific analyses as the user needs require. The flexibility and analysis power of digital data files used in conjunction with a GIS greatly facilitated the production of the maps. Furthermore, the GIS can be updated and modified in the future to produce maps based on new attenuation relationships as they are developed or new fault parameters as they are obtained.

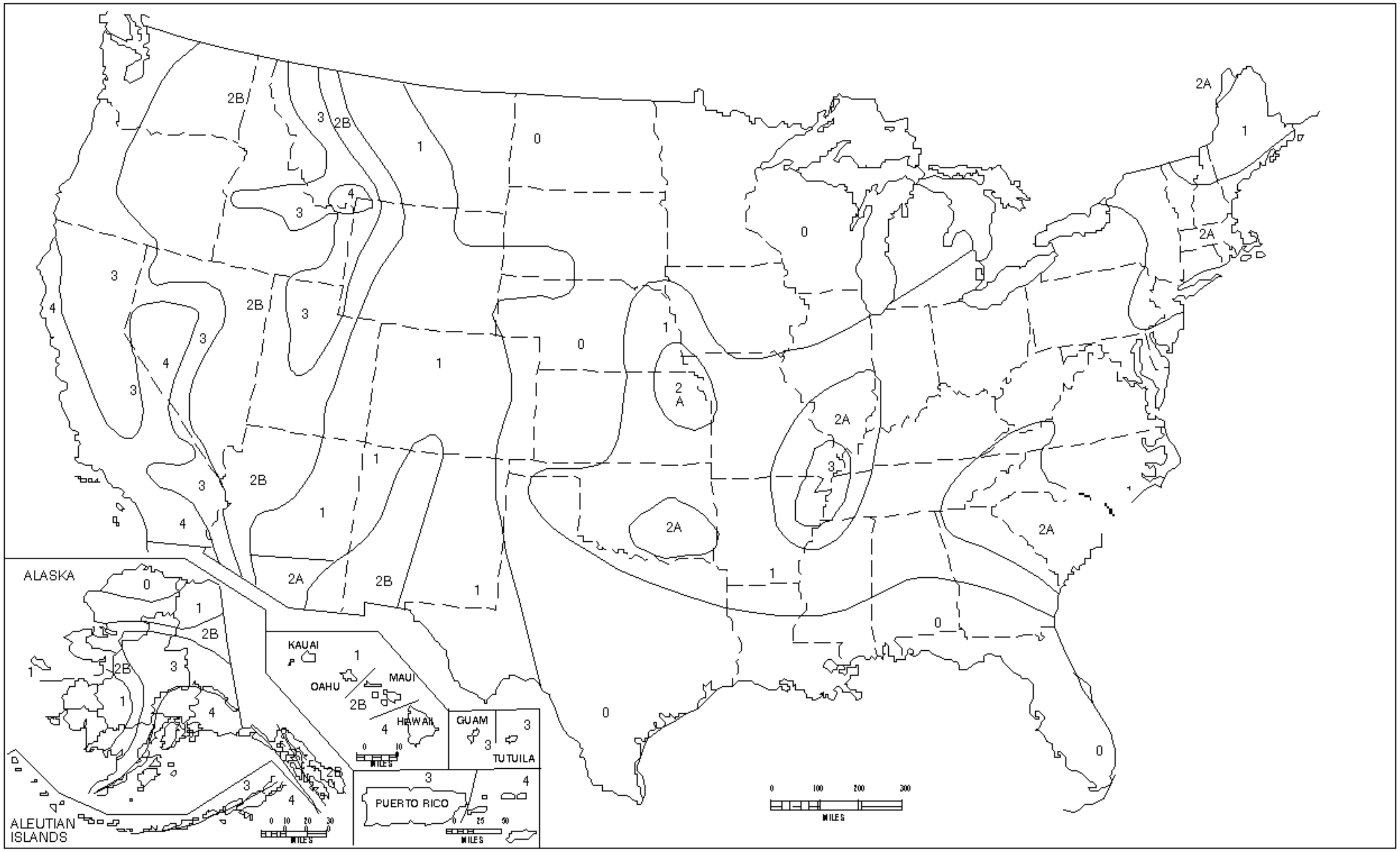

Figure 1. UBC seismic zone map of the United States. (Reproduced from the 1997 edition of the *Uniform Building Code*™, Volume 2, copyright © 1997, with the permission of the publisher, the International Conference of Building Officials).

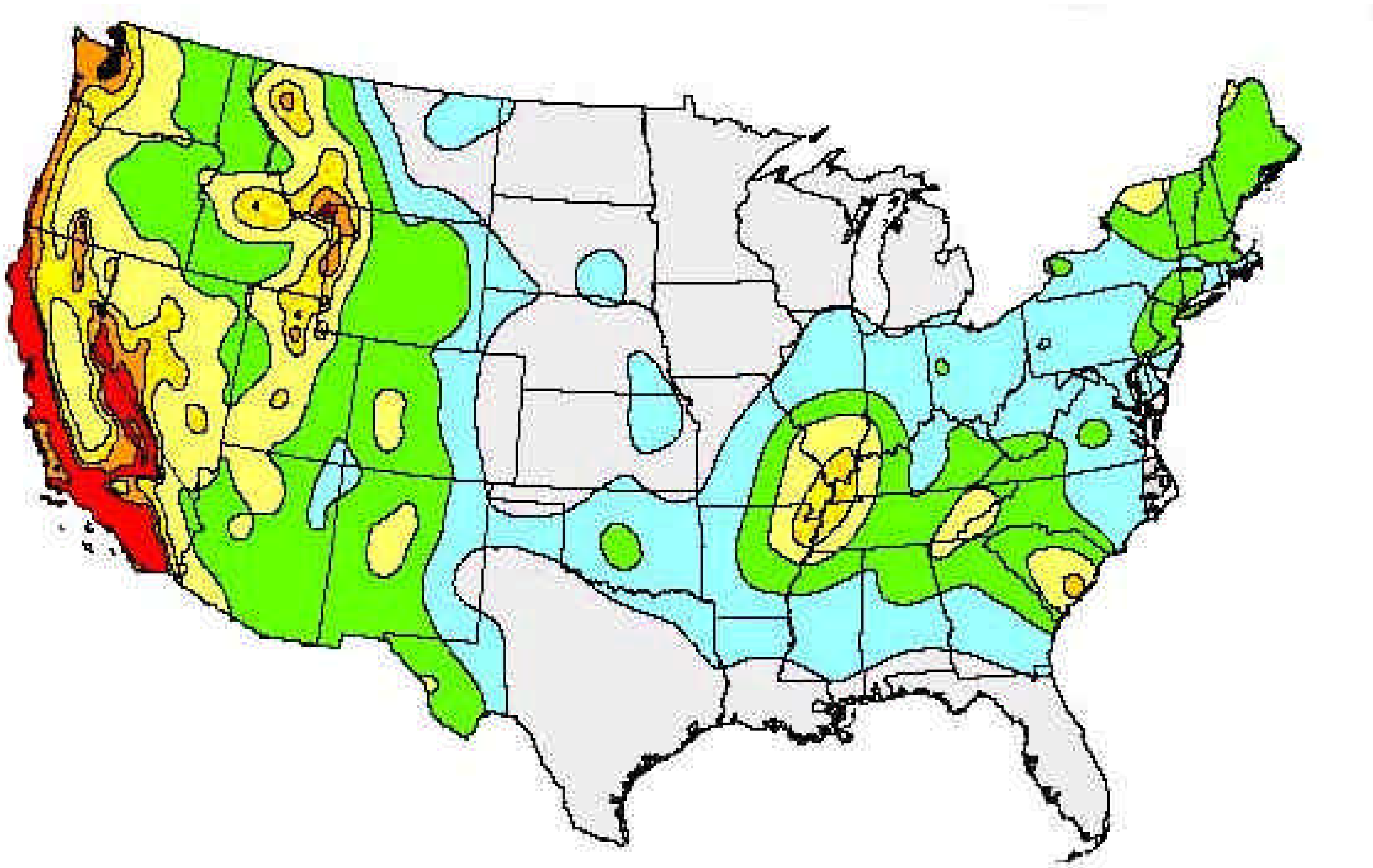

Figure 2. USGS PGA, 2% probability of exceedance in 50 years. (Reproduced from the *USGS National Seismic Hazards Mapping Project* web site with the permission of the publisher.)

PROCEDURES AND EQUATIONS

General Procedures

The steps used to determine peak bedrock acceleration at a single point are as follows:

1. Identify and characterize all seismogenic sources (location, length, dip, displacement/earthquake event).
2. Assign maximum considered earthquake magnitudes to each seismogenic source.
3. Calculate peak accelerations at each point using the appropriate site-to-source distance for the equation used and the magnitude of the source.
4. Compare results at each point from each seismic source and select the maximum value for the point.

To produce an accurate peak bedrock acceleration map for the state of Utah, peak acceleration must be calculated for a large number of points covering the entire state. Contours of peak acceleration can then be interpolated from these point values. The need for calculating acceleration values for a large number of points, the large number of seismic sources, and the desire to use multiple attenuation relationships required that the above procedure be automated as follows:

1. Create a grid of points at significant resolution for which values of peak bedrock accelerations will be calculated.
2. Calculate peak acceleration at each point on the grid for each seismic source and compare the value to the maximum for the grid point. Update maximum value so that the grid point always contains the maximum value.
3. Create contours of peak ground acceleration from the final grid data points.
4. Repeat steps 2 and 3 for all attenuation relationships.

Source Identification and Characterization

Maps and data for recently active faults had to meet several requirements to produce the desired results. First, seismic sources were considered to be faults with evidence of movement during Quaternary time. Second, the maps and data needed to be as complete and as recent as possible. Third, faults in states bordering Utah were included if they were close enough to cause strong ground shaking within Utah. The analysis was accomplished using ArcView GIS. Of the data acquired, only the faults in Nevada were in non-digital format. Data acquired in non-digital format were digitized and imported into ArcView.

Utah faults

The basis for the faults within Utah was a study done by the Utah Geological Survey (Hecker, 1993). This study included a map detailing the surface rupture traces of all known Quaternary faults in Utah and a table containing relevant information such as fault names, location reference numbers, slip rates, scarp heights, maximum estimated magnitudes, and other comments regarding each fault/fault zone on the map. The Utah state government maintains a digital database of geographic information using the UTM Zone 12 projection in ArcView format called the *State Geographic Information Database* (SGID). Hecker's (1993) fault map and related information are included as part of the existing SGID.

For the Utah portion of the analysis, Hecker's fault location numbers were used to identify individual faults and fault zones. The location numbers are based upon a grid Hecker used to separate the state into 13 areas, two degrees longitude by one degree latitude, numbered from 6 to 19. Hecker gave each fault or fault zone a number in the order it was digitized in its respective area. Thus the 12th fault digitized in area eight would have the unique location number of 812. Likewise, the fourth fault digitized in area 11 would have the unique location number of 1104, etc.

Faults in adjacent states

The ground motion attenuation relationships predict peak ground accelerations at relatively distant locations (up to 100 km) from source faults. Faults that had any part of their surface rupture trace within 100 km of the Utah state border were included in the analysis. Arizona, Nevada, Idaho, and Wyoming each had Quaternary faults that were included in the study. Neither the source for Colorado nor the sources for New Mexico showed Quaternary faults within 100 km of Utah at the time of this study.

Locations and data regarding Quaternary faults in Arizona were taken from Smith and Arabasz (1991) and Menges and Pearthree (1989). Quaternary faults in Nevada were taken from dePolo (1992) and Siddharthan et al. (1993). Quaternary faults in Idaho and Wyoming were taken from Smith and Arabasz (1991). The reference for Quaternary faults in Colorado and New Mexico was Frankel et al. (1996). Other references for Colorado and Wyoming were USGS (1992a, 1992b) digital computer files.

For consistency in location numbering, the faults/fault zones in adjacent states were numbered using the same Location Number convention as in Hecker's (1993) report with one change. Instead of using the numbered grid for the first part of the location number, each state outside of Utah was given a number not already used in Hecker's grid: Arizona = 1, Nevada = 2, Idaho = 3, Wyoming = 4. Colorado and New Mexico references did not show Quaternary faults within 100 km of Utah and were therefore not assigned a number. Faults or fault zones were then numbered consecutively, starting with 1, in each state. Thus, the eighth fault in Arizona would have the location number 108 and the 22nd fault in Idaho would have the location number 322, etc.

Ten fault traces from neighboring states cross the Utah border and match fault traces from the Utah map. These faults were considered to be continuous to ensure that the maximum considered event for each fault was consistent with fault length and Utah Location Numbers were maintained. The affected faults, based on location number, were numbers 611, 615, 616, 1001, 1003, 1007, 1101, 1104, 1108, and 1218.

Maximum Considered Earthquakes

The largest possible earthquake would have to occur to produce the maximum peak ground acceleration. The earthquake with the largest possible magnitude is considered to be the maximum considered earthquake. Earthquake magnitudes are predicted based upon fault size. The size of the fault determines the maximum amount of energy it can release in a seismic event. Larger faults, therefore, have potential for releasing greater amounts of seismic energy than smaller faults. The most complete study available for determining magnitudes is the research done by Wells and Coppersmith (1994) and was the basis for determining maximum considered earthquake magnitudes for the faults and fault zones in this study. Wells and Coppersmith stated:

> Seismic hazard analyses, both probabilistic and deterministic, require an assessment of the future earthquake potential in a region. Specifically, it is often necessary to estimate the size of the largest earthquakes that might be generated by a particular fault or earthquake source. It is rare, however, that the largest possible earthquakes along individual faults have occurred during the historical period. Thus, the future earthquake potential of a fault commonly is evaluated from estimates of fault rupture parameters that are, in turn, related to earthquake magnitude (Wells and Coppersmith, 1994, p. 974-975).

Wells and Coppersmith (1994) chose the following fault rupture parameters as the basis for their relationships: surface rupture length, subsurface rupture length, down-dip rupture width, rupture area, and maximum and average surface displacement. They used a database of 421 past earthquakes of various fault slip-types to create regressions that relate the above fault rupture parameters to moment magnitude. Regressions were calculated individually for strike-slip, reverse-slip, and normal-slip fault-type data sets. In addition, the data sets were combined to produce an all-slip-type relationship. In selecting the correct relationship, Wells and Coppersmith wrote:

> We observe no difference as a function of slip type at a 95% significance level (i.e., the regression coefficients do not differ at a 95% significance level) for relationships between surface rupture length and magnitude and subsurface rupture length and magnitude. For these relationships, using the all-slip-type relationships is appropriate because it eliminates the need to assess the type of fault slip. Furthermore, the uncertainty in the mean is smaller for the all-slip-type relationship than for any individual slip-type regression because the data set is much larger.
>
> The actual difference between the expected magnitudes that the [rupture width and rupture area] regressions provide typically is very small. Differences of more than 0.2 magnitude units occur only at magnitudes less than M 5.0. Because the difference in these magnitude estimates is small, the all-slip-type relationship for rupture area versus magnitude is appropriate for most applications. The difference between magnitude estimates for rupture width versus magnitude estimates also is small, thus, the all-slip-type relationship again is preferred for most applications (Wells and Coppersmith, 1994, p. 994).

Shown in Table 2A of Wells and Coppersmith (1994) are the ranges of applicability for each equation. The range for the surface rupture length relationship increases from 41 km to 432 km when using the all-slip-type in place of the normal-slip-type relationship. Based on the recommendations above and the range restrictions, the all-slip-type relationships were used to calculate magnitude by surface rupture length and rupture area.

Wells and Coppersmith (1994) also wrote that regressions for displacement relationships show larger differences as a function of slip type, therefore relationships for normal-slip-type were used whenever maximum and average displacement data were available for a specific fault.

Surface rupture length and magnitude

Shallow, large-magnitude earthquakes cause ruptures on the earth's surface. The length of these ruptures can be correlated with the magnitude of the earthquake that produced them. The all-slip-type equation relating surface rupture length to moment magnitude is:

$$M = 5.08 + 1.16 \log (SRL) \qquad with\ s = 0.28$$

Where, *SRL* = surface rupture length (km)
σ = 1 standard deviation

Rupture area and magnitude

Wells and Coppersmith (1994) define the rupture area (RA) as the subsurface rupture length (RLD) multiplied by the down-dip rupture width. Wells and Coppersmith used the early aftershock zone to define the length of the subsurface rupture. In cases where aftershock data were unavailable, they estimated that surface rupture length averaged about 75% of the subsurface rupture length (Wells and Coppersmith, 1994). Down-dip rupture width is estimated from the depth (thickness) of the seismogenic zone or the depth of the hypocenter and the assumed dip of the fault plane (Wells and Coppersmith, 1994). For this study, the depth of the seismogenic zone is considered to be 15 kilometers and the dip angle of the fault is taken to be 60 degrees:

Down-dip width = 15 km / sin (60°) = 17.3 km
RLD = SRL / 0.75

Therefore,
RA = RLD x down-dip width = (SRL) 0.75) x 17.3 km

Given this definition, the following equation relates rupture area to moment magnitude for all-slip-types:

$$M = 4.07 + 0.98 \log (RA) \qquad with\ s = 0.24$$

Where

M = moment magnitude

RA = rupture area (km^2)

ó = 1 standard deviation

Surface displacement and magnitude

Surface displacement along the fault is related to the magnitude of the seismic event. Either maximum or average surface displacement values can be used in their appropriate equations to estimate Maximum Considered Earthquakes. For the Wells and Coppersmith (1994) study, net maximum displacements were calculated using components of horizontal and vertical slips. The next two equations relate maximum surface displacement with magnitude for normal faults and average surface displacement with magnitude for normal faults, respectively:

$$M = 6.61 + 0.71 \log (MD) \qquad with\ s = 0.34$$

$$M = 6.78 + 0.65 \log (AD) \qquad with\ s = 0.33$$

where

M =	moment magnitude
MD =	maximum surface displacement (m)
AD =	average surface displacement (m)
ó =	1 standard deviation

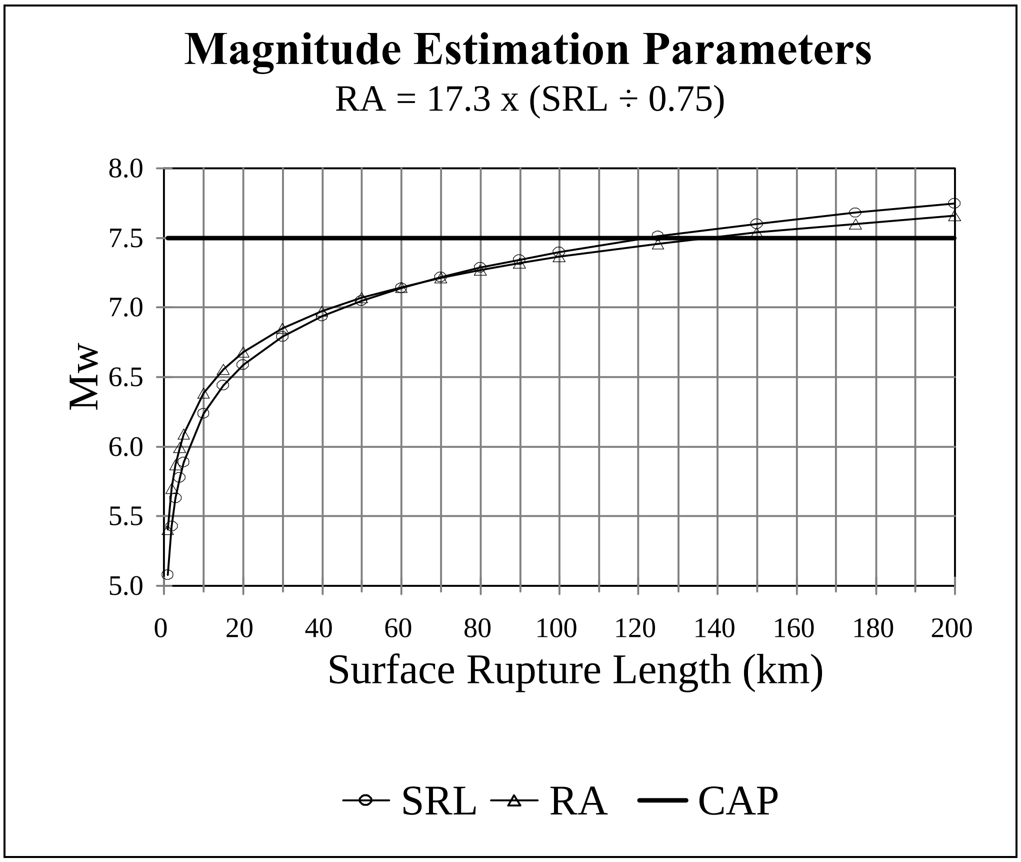

Figure 3. Magnitude estimation parameters comparison

Figure 3 compares the predicted magnitudes from surface rupture length and rupture area. The values shown are plotted against surface rupture length where rupture area = SRL/0.75 x 17.32. The relationship giving the highest magnitude event for each particular fault controls the assignment of magnitude. As seen in Figure 3, the rupture area equation controls magnitude assignment for faults with lengths up to about 45 km. Beyond lengths of 45 km, the surface rupture length equation controls magnitude assignment. However, the displacement equations often controlled selection of magnitude in cases where displacement data was available.

Strong Motion Equations

Attenuation relationships are used to calculate peak acceleration, accounting for reductions (or amplifications) due to the distance seismic waves travel and the medium through which they travel. Attenuation equations are primarily functions of earthquake magnitude (*M*) and distance (*r*) from the event. Other functions, such as fault type and medium (soil, rock), have been used by some researchers in developing statistically significant parameters for attenuation equations.

Many relationships have been developed for predicting strong ground motion and many of these can be applied to specific tectonic regimes or fault types. Therefore, the selection of attenuation relationships for use in Utah was critical. Many early relationships were based primarily upon earthquake data collected from strike-slip zones such as California. Relationships based on strike-slip data may not predict strong ground motion in extensional regimes, such as Utah, with the desired precision. Spudich et al. (1996) wrote:

> There is observational evidence that the state of stress, extensional or compressional, affects the amplitude of the ground motion from an earthquake. McGarr (1984) suggested that normal faulting events have lower motions than strike slip events (Spudich et al., 1996, p. 190).

Three relationships were selected for analysis and comparison. Two relationships developed for use in extensional or normal faulting regimes were chosen: the Spudich et al. (1996) relationship and the Abrahamson and Silva (1997) relationship. Also included, for comparison purposes, were relationships by Campbell (1997). Of these relationships, Sea96 does not include an equation to calculate the vertical component of peak ground acceleration.

Sea96 relationship

Spudich et al. (1996, 1997) developed the Sea96 relationship for predicting earthquake ground motions in extensional tectonic regimes. The earthquake data set used by Spudich et al. included only earthquakes from faults in extensional regimes. The earthquakes were of magnitude 5 and greater at distances less than 105 kilometers. This makes Sea96 an ideal relationship for use in Utah. The Sea96 relationship gives equations for the horizontal component of peak ground acceleration only. Given the magnitude of a seismic event, and the distance from the source, one can determine the peak ground acceleration at that point using equations S-1 and S-2:

$$\log_{10} Y = b_1 + b_2 (M - 6) + b_3 (M - 6)^2 + b_4 R + b_5 \log_{10} R + b_6 \Gamma \qquad \text{S-1}$$

$$R = \sqrt{r_{jb}^2 + h^2} \qquad \text{S-2}$$

where

$Y =$ horizontal peak ground acceleration in % gravity (g)

$M =$ moment magnitude of seismic event

r_{jb} = Joyner-Boore site to source distance

h = depth (given by Spudich *et al.*)

Ã = site condition variable

Equation S-3 gives the standard deviation of $\log_{10}$Y:

$$s_{logY} = \sqrt{s_1^2 + s_2^2} \qquad \text{S-3}$$

Adding $ó_{logY}$ to the right side of Sea96, before solving for *Y,* gives peak ground acceleration plus one standard deviation. The variables b_1, b_2, b_3, b_4, b_5, b_6, *h*, $ó_1$, and $ó_2$ are regression coefficients given by Spudich et al. Table 1 shows the values used for this study. The variable gamma is used to determine site class. Ã is 1 for soil sites and 0 for rock sites. Since this study was only concerned with accelerations at bedrock level, Ã was set to 0.

Selection of the Sea96 relationship was primarily for its specific applicability in extensional regimes. Unfortunately, the Sea96 relationship does not include equations to calculate the vertical component of peak ground acceleration. This limits its utility in the present study.

Table 1. Regression coefficients for Sea96

b_1	b_2	b_3	b_4	b_5	b_6	*h(km)*	$ó_1$	$ó_2$	$ó_3$
0.156	0.229	0.000	0	-0.945	0.077	5.57	0.216	0	0.094

Abrahamson and Silva relationship

The Abrahamson and Silva (1997) relationship was determined using a database of multiple recordings of 58 earthquakes. Although not specifically designed for extensional regimes as the Sea96 relationship, the Abrahamson and Silva relationship does differentiate between strike-slip, reverse, and all other fault mechanisms and includes a factor to distinguish between ground motions on the hanging wall and footwall sides of a fault. In a subsequent publication, Abrahamson added a reduction factor for normal-fault events (Abrahamson and Becker, 1997). Whereas the Sea96 relationship can only be used for the horizontal component of peak ground acceleration, the Abrahamson and Silva relationship can be used to calculate either horizontal or vertical components of peak ground acceleration. Given the magnitude of a seismic event, and the distance from the source, the peak ground acceleration at a point for a normal fault can be determined using equation AS-1 from Abrahamson and Silva (1997), adding the normal-fault factor from Abrahamson and Becker (1997):

$$\ln Sa(g) = f_1(M, r_{rup}) + F_1 f_3(M) + F_3 a_{14} + HWf_4(M, r_{rup}) + Sf_5(pga_{rock}) \qquad \text{AS-1}$$

where

$Sa(g)$ =	spectral acceleration in % g (horizontal or vertical peak ground acceleration is the zero period spectral value)
M =	moment magnitude of a seismic event
r_{rup} =	source-to-site distance (described later)
F_1 =	style of faulting factor
F_3 =	normal-fault factor
HW =	hanging wall effect factor
S =	site response factor

The variable F_1 represents the type of fault. F_1 = 1 for reverse faults, 0.5 for reverse/oblique, and 0 for all other faults. F_3 is the normal fault factor added by Abrahamson and Becker (1997), and is 1 for normal faults and 0 for all other fault types. HW is a hanging wall factor used with dipping faults. HW is 1 for sites over a hanging wall and 0 otherwise. S is 0 for rock and shallow soil, 1 for deep soil. Function $f_1(M, r_{rup})$, shown in equation AS-2, is the base function. It is dependent on both magnitude and distance:

$$\text{for } M \le c_1$$
$$f_1(M, r_{rup}) = a_1 + a_2(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)] \ln R \qquad \text{AS-2}$$

$$\text{for } M > c_1$$
$$f_1(M, r_{rup}) = a_1 + a_4(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)] \ln R \qquad \text{AS-3}$$

Where $R = \sqrt{r_{rup}^2 + c_4^2}$

Utah faults are primarily normal faults so fault type variable F was set to zero. Therefore, function $f_3(M)$ becomes zero and was not needed. The hanging wall variable HW, however, was set to 1 for the locations on the hanging wall side of each fault, and ramped to zero nonlinearly for grid points near the ends of faults. This allows for a smooth transition from the hanging wall side to the footwall side of each fault. Therefore, $f_4(M, r_{rup})$ was used where necessary. Abrahamson and Silva define the function f_4 (M, r_{rup}) as shown in equation AS-4:

$$f_4(M, r_{rup}) = f_{HW}(M)\, f_{HW}(r_{rup}) \qquad \text{AS-4}$$

where

$$f_{HW}(M) = \begin{cases} 0 & \text{for } M < 5.5 \\ M - 5.5 & \text{for } 5.5 < M < 6.5 \\ 1 & \text{for } M > 6.5 \end{cases}$$

and

$$f_{HW}(r_{rup}) = \begin{cases} 0 & \text{for } r_{rup} < 4 \\ a_9 \dfrac{r_{rup} - 4}{4} & \text{for } 4 < r_{rup} < 8 \\ a_9 & \text{for } 8 < r_{rup} < 18 \\ a_9 \left(1 - \dfrac{r_{rup} - 18}{7}\right) & \text{for } 18 < r_{rup} < 24 \\ 0 & \text{for } r_{rup} > 25 \end{cases}$$

Since this study was seeking peak ground accelerations on rock sites, the site class variable S was set to zero. Function f_5 is multiplied by S, and therefore not needed. The magnitude dependent equation AS-5 gives the standard deviation for the Abrahamson and Silva relationship:

$$\acute{o}_{total}(M) = \begin{cases} b_5 & \text{for } M < 5.0 \\ b_5 - b_6(M-5) & \text{for } 5.0 < M < 7.0 \\ b_5 - 2b_6 & \text{for } M > 7.0 \end{cases} \qquad \text{AS-5}$$

The variables a_1, a_2, a_3, a_4, a_9, a_{12}, a_{13}, c_1, c_4, c_5, n, b_5, and b_6 are regression coefficients given in Abrahamson and Silva (1997). Regression coefficient a_{14} is given in Abrahamson and Becker (1997). The regression coefficients differ for calculating the horizontal or vertical component of ground acceleration at a period of 0.01 s, which was taken to represent peak conditions. Tables 2 and 3 show the values used for this study.

<u>Campbell relationships</u>

Campbell (1997) combined previously published relationships (Campbell, 1989; Campbell and Bozorgnia, 1994) to develop a more comprehensive set of

Table 2. Regression coefficients for Abrahamson & Silva (Abrahamson and Silva, 1997; Abrahamson and Becker, 1997).*

Component.	a_1	a_2	a_3	a_4	a_9	a_{12}	a_{13}	a_{14}	c_1	c_4	c_5	n
Horiz.:	1.640	0.512	-1.1450	-0.144	0.370	0.0	0.17	-0.16	6.4	5.6	5.6	2
Vert.:	1.640	0.909	-1.2520	0.275	0.630	0.0	0.06	-0.25	6.4	6.0	0.3	3

*period = 0.01 s

Table 3. Coefficients for standard errors for Abrahamson and Silva (1997).*

Component	b_5	b_6
Horizontal	0.70	0.135
Vertical	0.76	0.085

*period = 0.01 s

relationships for predicting horizontal and vertical components of strong ground motion. Like the Abrahamson and Silva relationship, the Campbell relationships were not specifically designed for extensional regimes, but they distinguish between strike-slip and reverse, thrust, reverse-oblique, and thrust-oblique faults. Using the Campbell equations to model normal faults is discussed below. The Campbell relationships can be used to determine both horizontal and vertical components of peak ground acceleration. The relationships for peak ground acceleration as defined by Campbell (1997) are given by equations C-1 and C-2:

$$\ln(A_H) = -3.512 + 0.904\,M - 1.328 \ln\sqrt{R_{seis}^2 + [0.149 \exp(0.647\,M)]^2} \qquad \text{C-1}$$

$$+ [1.125 - 0.112 \ln(R_{seis}) - 0.0957\,M]\,F$$

$$+ [0.440 - 0.171 \ln(R_{seis})]\,S_{SR}$$

$$+ [0.405 - 0.222 \ln(R_{seis})]\,S_{HR} + e$$

or

$$\ln(A_V) = \ln(A_H) - 1.58 - 0.10\,M \quad - 1.5 \ln[R_{seis} + 0.079 \exp(0.661\,M] \qquad \text{C-2}$$

$$+ 1.89 \ln[R_{seis} + 0.361 \exp(0.576\,M)]$$

$$- 0.11\,F + e$$

where

A_H = peak ground acceleration g, horizontal component

A_V = peak ground acceleration g, vertical component

M = moment magnitude of seismic event

R_{seis} = source-to-site distance described below

F = style of faulting factor

S_{SR} and S_{HR} = factors for local site conditions

å = random error term with a mean of zero

Style of faulting factor, F, is used to identify the type of fault. $F = 0$ for strike-slip faults and $F = 1$ for reverse, thrust, reverse-oblique, and thrust-oblique faults. Additionally, Campbell wrote:

> There were only two normal-faulting earthquakes included in the current database used to determine the coefficient of F. Therefore, there is no statistical basis in this study for concluding whether strong ground motions from normal-faulting earthquakes are different from those of other types of earthquakes. However, considering the recent empirical results cited above, it is recommended that normal-faulting earthquakes be assigned a value of F halfway between that of strike-slip and reverse-faulting earthquakes, or $F = 0.5$, until more definitive studies become available (Campbell, 1997, p. 156-157).

Based on the above statement, F was given the value of 0.5 for this study. The local site condition factors S_{SR} and S_{HR} are used to define site class. $S_{SR} = S_{HR} = 0$ for firm soil; $S_{SR} = 1$ and $S_{HR} = 0$ for soft rock; and $S_{SR} = 0$ and $S_{HR} = 1$ for hard rock. For this study, production of peak bedrock acceleration maps, the soft rock condition applied. The random error term å is given a mean of zero by Campbell and therefore set to zero for this study. The standard error, ó, for the horizontal component $\ln(A_H)$ of equation C-1, can be determined using equation C-4a, relating ó to peak ground acceleration (A_H) or by equation C-4b, relating ó and magnitude (M):

ó = 0.55. for $A_H < 0.068$ g

$0.173 - 0.140\ln(A_H)$ for 0.068 g $< A_H$ 5.5 < 0.21 g C-4a

0.39 for $A_H > 0.21$ g

$0.889 – 0.069M$ for $M < 7.4$ C-4b

0.38 for $M > 7.4$

Campbell stated that equation C-4a is statistically more robust than equation C-4b with an r-squared value of 0.89. By comparison, equation C-4b has an r-squared value of 0.56 (Campbell, 1997). Either equation may be used to determine *ó*. Equation C-4b, relating *ó* to *M*, was used in this study for several reasons. First, it was easier to implement in the program code written to automate the analysis. Second, despite the fact that C-4a is more statistically robust than C-4b, the difference between the two equations was minimal (for a 7.0 M earthquake, the maximum difference in PGA + 1 sigma was only 0.015g). The standard error for the vertical component (equation C-2) is a function of the horizontal standard error. It is shown in equation C-5:

$$s_V = \sqrt{s^2 + 0.36^2} \qquad \text{C-5}$$

where, ó$_V$ = standard error for $\ln(A_V)$

ó = standard error for $\ln(A_H)$

Either *ó* or ó$_V$ must be added to the right side of their respective equations before solving for 84th percentile peak horizontal or vertical ground acceleration.

Comparisons of relationships

Each of the above relationships was derived using different regression techniques and different data sets. Therefore, it is to be expected that the results will vary one from another. Figure 4 shows the differences between the predicted peak bedrock accelerations, on the hanging wall side, for each relationship. The peak in the Abrahamson and Silva relationship shows predicted values of peak ground acceleration if the Hanging Wall factor were added. Both the Sea96 and Campbell relations have plateaus, characterized by their respective site-to-source distance measurements used in the equations.

On the footwall side, the Sea96 relationship would be shifted, thus having no plateau. Also, the hanging wall factor would not be added to the Abrahamson and Silva relationship. From Figure 4, it is obvious that there is some disparity in the near-field prediction of peak ground acceleration. This is probably due to the limited amount of data available in the near field from which to create regressions.

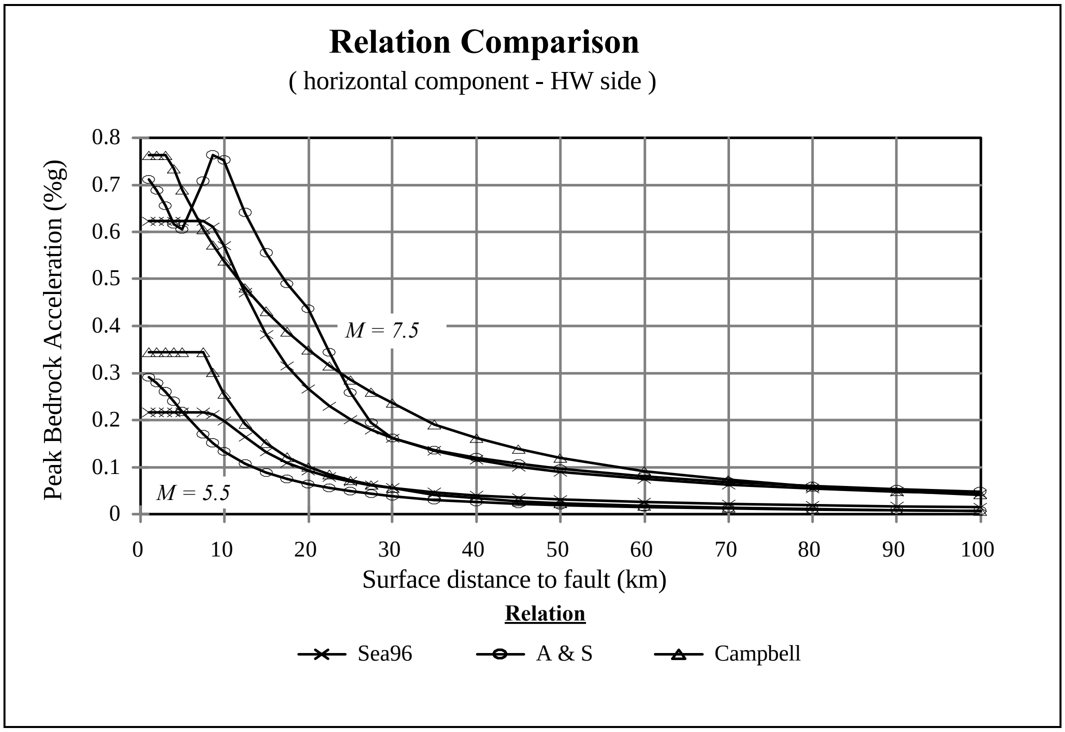

Figure 4. Attenuation relation comparison.

Source-to-site distance

Each relationship includes its own source-to-site distance definition (r) from the seismic event to the grid point or site. The Sea96 relationship uses $r_{jb,}$ the closest horizontal distance to the vertical projection of the rupture. The Abrahamson and Silva relationship uses r_{rup}, the closest distance to the rupture. The Campbell relationship uses R_{seis}, the closest distance to the seismogenic rupture surface. Figure 5 shows graphically the different distance definitions used in the various equations.

Although used differently in their respective relationships, the distance variables r_{rup} and R_{seis} use essentially the same definition. Each is measured from the surface along a line perpendicular to the fault plane. For cases where the perpendicular line would be projected below the depth of the rupture area, r_{rup} and R_{seis} are measured from the bottom of the surface rupture. As an additional restriction on R_{seis}, Campbell stated: "By definition, R_{seis} cannot be less than the depth to the top of the seismogenic part of the earth's crust. This depth should be no shallower than about 2 to 4 km. It can, however, be greater than this range"(Campbell, 1997, p. 155-156).

The depth to seismogenic rupture is the depth at which the fault plane ceases to radiate seismic energy as a result of fault rupture. Campbell (1997) has suggested the maximum depth to the bottom of the zone of seismogenic rupture should be no greater than 15 km. This depth probably corresponds to the brittle-ductile transition in Utah. Earthquakes do not occur deeper than this because deformation is occurring in ductile rock, which can deform without releasing seismic energy. Above this depth, the crust is brittle and therefore ruptures release seismic energy. For this study, the maximum depth of rupture was set at 15 km as suggested by Campbell. Additionally, the dip angle of each fault was generalized to be sixty degrees. Using the 60° dip angle and 15 km depth, r_{rup} and R_{seis} are calculated.

Distance variable r_{jb} is always a surface distance to the area of zero distance. The area of zero distance is shown in Figure 5 where r_{jb} equals zero. On the footwall side, all measurements are taken from the surface rupture, and again R_{seis} cannot be less than d_{seis}, and d_{seis} cannot be less than 3 km (Campbell, 1997).

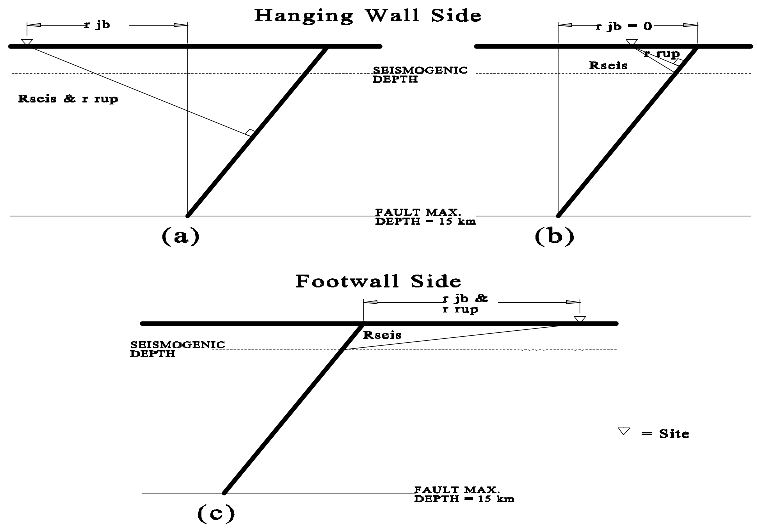

Figure 5. Source-to-site distance definitons

Determining Maximum PGA at a Point

To determine maximum values of peak ground acceleration at a single point, peak ground acceleration values are calculated at the point for each seismic source using the selected strong motion equation, its appropriate site-to-source distance definition, *r*, and the MCE assigned each source. The calculated values of peak ground acceleration are compared and the maximum peak ground acceleration value is selected for that point.

With the site-to-source distance and the appropriate curve, peak ground acceleration at the site can be determined from each curve. The values are compared and the maximum is selected.

Peak acceleration is determined by magnitude *and* distance. It can be seen that the highest peak ground acceleration value at a site is not always produced by the fault closest to the site, or by the fault with the largest MCE in the area. Thus, it is not always apparent which event will produce peak acceleration values.

ANALYSIS

The analysis was conducted using ArcView GIS and its Spatial Analyst extension. The analysis tools in ArcView and Spatial Analyst allow for the display of spatial data (such as fault locations), the creation of a grid of points over the area in question, and the use of a database of fault parameters for calculating values for points on the grid. The grid resolution is easily selected by the user, as well as the parameters to be analyzed. Additionally, the programming language Avenue was used with ArcView to automate the procedures and repeat them for each selected fault.

Magnitude Assignment

Wells and Coppersmith (1994) defined surface rupture length as follows:

> Primary surface rupture is defined as being related to tectonic rupture, during which the fault rupture plane intersects the ground surface. Discontinuous surface fractures mapped beyond the ends of the continuous surface trace are considered part of the tectonic surface rupture and are included in the calculation of surface rupture length. (Wells and Coppersmith, 1994, p. 984)

The length of each fault or fault zone was measured digitally in kilometers from its extreme ends within ArcView. Figure 6 shows an example surface rupture trace of a fault zone and the length measurement used for the Wells and Coppersmith (1994) equations.

Additionally, Hecker's (1993) report includes a table with relevant information for each of the faults/fault zones that were identified in Utah, including fault length (km), displacement per event (m), and scarp height (m) where available. Displacement-per-event values were sometimes given as a range between two values. The maximum of the range was taken as the maximum displacement (*MD*) variable in the Wells and Coppersmith equations. Scarp height was also used for the maximum displacement variable when it was clear that it represented a single earthquake event. Values from Hecker were included in magnitude calculations whenever practical.

Using the measured fault dimensions data and the information given by Hecker, magnitudes were calculated using the Wells and Coppersmith equations. The values from each equation were compared, and the maximum of the calculated values was then selected as the magnitude for the Maximum Considered Earthquake for that particular fault/fault zone. Magnitude values were capped at 7.5, because recorded normal faulting events have never been shown to produce earthquakes of magnitudes greater than this value. This cap affected many faults in Nevada and only the longest of faults in Utah.

Values for MCE plus one standard deviation were also calculated using this same procedure for each fault. The results were inserted into the fault parameter database used in the final calculations of peak bedrock acceleration.

A background earthquake was NOT considered for this study. Information on background earthquakes in Utah can be found in Arabasz, et al. (1992) and Pechmann and Arabasz (1995).

Three sets of faults zones in Utah had separate location numbers assigned to different parts of the same fault zone. In these cases, magnitudes were calculated for each of the individual parts, and the maximum of the individual parts was assigned to all parts of the fault zone in question. The faults affected in such a way were location numbers 906, 910, 911; 1117, 1118, 1119; and 1305, 1306, 1307.

A number of folds (monoclines, anticlines, and synclines) were included in Hecker's (1993) analysis as having formed during the Quaternary. Magnitudes for these features were assigned using the Wells and Coppersmith equations as done for faults but were given a cap of $M_W = 6.25$. This value

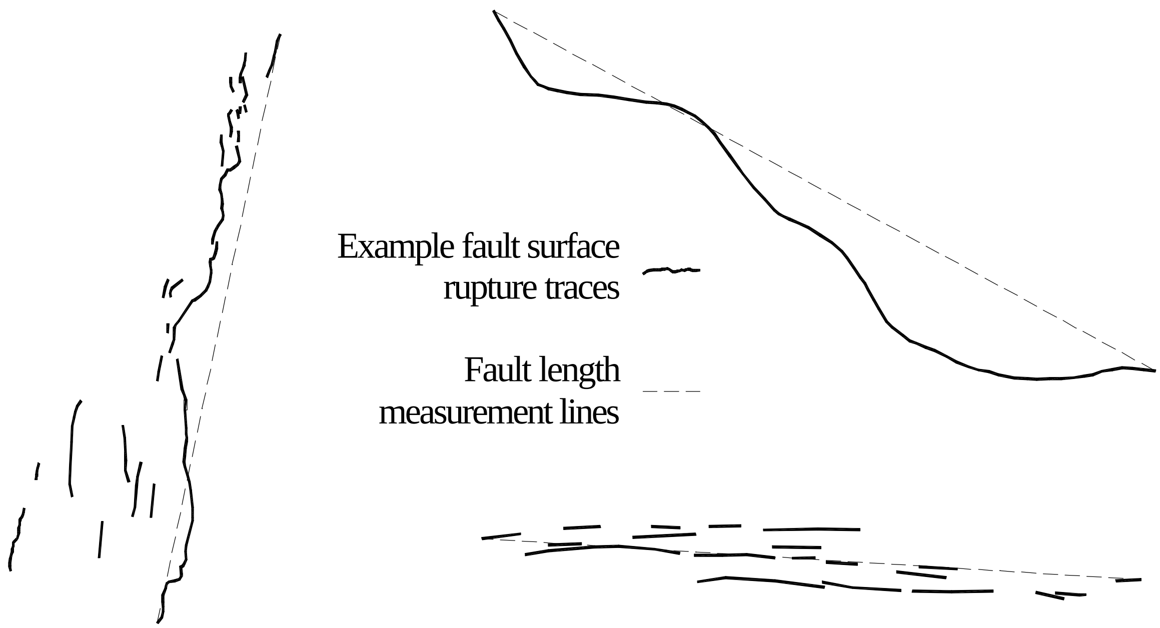

Figure 6. Typical fault length measurements

represents the maximum magnitude at which earthquakes occur without causing surface rupture. Assigning magnitudes at the threshold of surface rupture accounts for their presence and is a conservative estimate of their siesmogenic potential.

A number of faults identified in Hecker's (1993) report were cited as having questionable siesmogenic potential. The majority of these faults are located in eastern Utah where the faults are attributed to salt diapirs or salt dissolution and flow instead of actual tectonic faulting. These faults were not included in the peak bedrock acceleration calculations.

Fault Parameter Database

A database was created containing all necessary fault parameters needed in peak ground acceleration calculations. The information in this database was used in the scripts written for ArcView to automate the calculation procedure. Fault parameters included in the database were Locnum, Name, *Mw*, *Mw* + *ó*, State, dip-dir, dip-model, dip-angle, and length for each fault/fault zone. A description of each field in the database is shown in Table 4. Appendix A contains the complete database used for the analysis.

Grid Resolution

Similar to production of topographic maps from discrete elevation data points, discrete data points of peak ground acceleration can be used to create a contour map of peak bedrock acceleration. The quantity and density at which the data points are sampled greatly affect how accurately the interpolated surface matches the actual surface. Ideally, as the number of points approaches infinity, the interpolated surface approaches the existing surface. However, existing limitations on data storage, computational power, and other restrictions set practical limits on the quantity and spacing of data points. The law of diminishing returns, an economic principle, asserts that the application of additional units of any one input to fixed amounts of the other inputs yields successively smaller increments in the output of a system of production.

Table 4. Description of fault parameter database fields

Field	*Description*
Locnum	The script was programmed to select each fault by location number. Thus if a single fault consists of multiple surface trace segments, all segments with the same location number are analyzed together.
Name	If the name of the fault or fault segment was known, it was included in the table for reference only.
Mw	Mw is the maximum considered earthquake as calculated using the Wells and Coppersmith equations as described previously. The largest calculated MCE from each of the equations was used for each fault. This field or the MCE + 1 ó field is selected as the earthquake magnitude value for use in the attenuation equations.
Mw + ó	Mw + ó is the maximum considered earthquake plus one standard deviation as calculated using the Wells and Coppersmith equations. The largest calculated MCE + 1 ó from each of the equations was used for each fault. This field or the MCE field is selected as the earthquake magnitude value for use in the attenuation equations.
State	The state in which the fault is located was included as part of the table. This field was included for reference and selection purposes only.
Dip direction	Dip direction was assigned each fault based on topography. This field tells the program which direction on a 16 point compass that the fault dips. This field is used in the calculation of r_{rup}, r_{seis}, or r_{jb} .
Dip Model	This field tells ArcView to model the fault as single dipping in the dip direction (1), or on both sides of the fault(2), or not at all (0). If dip direction was difficult to determine based on topography, the fault was modeled as dipping on both sides to be conservative. Faults to be excluded from the analysis were given a “0” tag. This field is used in the calculation of r_{rup}, r_{seis}, or r_{jb} .
Dip Angle	This field tells the program the down-dip angle of the fault. This field is used in the calculation of r_{rup}, r_{seis}, or r_{jb} .
Length	This field gives the surface rupture length measurement used to determine the MCE assigned to the fault. This field is not used in the program scripts at this point but could be implemented later to calculate magnitude as new or updated magnitude prediction relationships become available.

For this study, a grid spacing of 1 km was used over the entire state, resulting in approximately 230,000 points at an appropriate density to produce the desired contours of peak acceleration. Setting a finer grid spacing did not produce significantly better results at a statewide scale, and was therefore not justified. For studies on more localized areas, a finer resolution should be considered.

Automation

Because of the large number of sites (points on the grid) for which peak accelerations were to be calculated, the procedure described in the section Determining Maximum PGA at a point was automated by writing program scripts with ArcView's Avenue programming language. A separate script was written for each of the attenuation relationships. The code for each can be found in Appendix B. Each script was structured generally as follows:

Before running any script, the faults to be analyzed are selected by the user either graphically or by querying the fault parameter database. If the user selects no faults, all faults are selected by default.

1. Choose to calculate horizontal or vertical component of PGA (vertical not available with Sea96).
2. Select table (fault parameter database) containing fault and analysis parameters (includes fault specific magnitudes).
3. Select the fields from the table containing the appropriate fault parameter data.
4. Set attenuation relationship regression coefficients or accept default values for PGA.
5. Choose whether or not to add one standard deviation to PGA calculations.
6. If not already set, select grid size, location, and resolution for the analysis.
7. Begin analysis loop (see appendix C).
    - A. Select first (or next) fault in selection set for analysis.
    - B. Query and assign the fault magnitude and fault parameters from table.
    - C. Convert the fault line trace to grid data.
    - D. Calculate distance grid from the fault grid data.
    - E. Calculate aspect grid for use in determining if grid cell is on hanging wall side or footwall side of fault (used with the Campbell (1997) and Abrahamson and Silva (1997) relationships).
    - F. Calculate peak ground acceleration grid for this fault using distance grid, magnitude assignment, and aspect grid (if necessary) in the attenuation equation.
    - G. If the fault is modeled dipping on both sides, repeat steps a-f for the other side, then continue.
    - H. If the fault is the first fault to be analyzed, set maximum PGA for the grid equal to fault PGA grid. If not first, compare fault PGA grid to maximum PGA for the grid point and update the maximum PGA grid using maximum values.
    - I. If not last fault, go back to step a., or else end analysis loop.
8. Create a Grid Theme in ArcView GIS from maximum PGA grid values and add it to the map view.

The user then generates contour lines from maximum PGA grid values at desired contour interval using the *Generate Contours* function in ArcView's Spatial Analyst.

Uncertainties

Four options were available to express uncertainties in magnitude and peak ground acceleration calculations. The Wells and Coppersmith (1994) equations used to calculate magnitude provided for the addition of one standard deviation to the magnitude. This magnitude value could then be used in the attenuation relationships. Additionally, each attenuation relationship also provides for the addition of one standard deviation to the calculated peak ground acceleration. Therefore, the final calculations could be executed based on one of the four following possibilities:

1. Mean magnitude and mean peak ground acceleration
2. Mean + one standard deviation magnitude and mean peak ground acceleration
3. Mean magnitude and mean + one standard deviation peak ground acceleration
4. Mean + one standard deviation magnitude and mean + one standard deviation peak ground acceleration

Comparisons of options 1 through 4 are shown in Figures 7, 8, and 9 for each of the attenuation relationships used. A mean magnitude of 7.0 was arbitrarily chosen for the calculations to produce the figures, with one standard deviation added for option 2 and 4. Option 3 was considered to be the most useful representation of maximum peak acceleration because mean values of earthquake magnitude appear to be reasonable based on the geologic and tectonic setting of Utah, but the attenuation of strong ground motion is associated with considerable uncertainty.

The analysis procedures also created some uncertainty. ArcView's Spatial Analyst tools required line traces of faults to be converted into grid entities at the same resolution as the calculation grid. This forces each fault trace in the model to have the same width as the calculation grid cell. For map display at a statewide scale, the error associated with a 1-km cell dimension is negligible. For further discussion on the conversion of line features to grid features, see Appendix C.

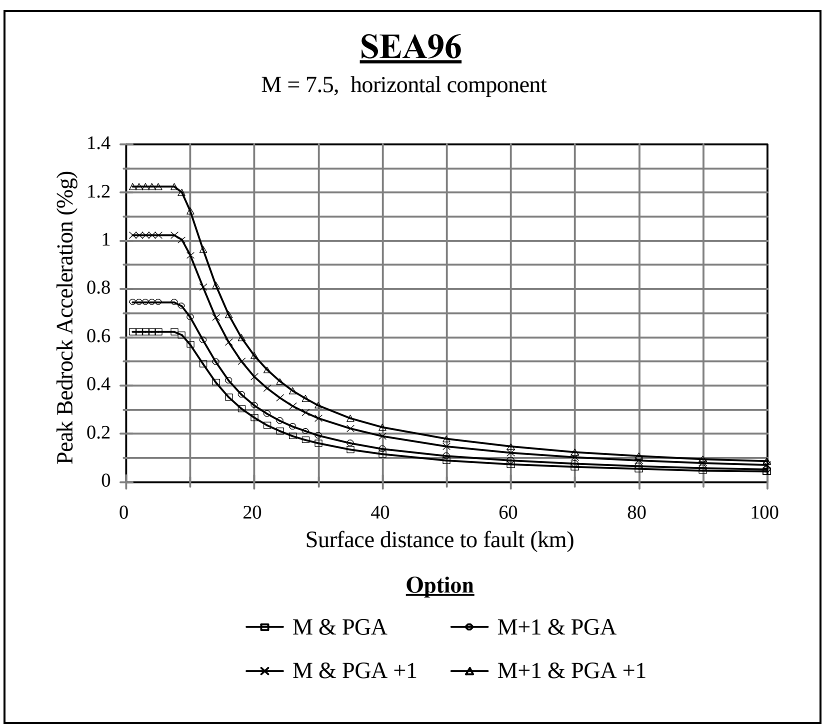

Figure 7. Uncertainty options and SEA96 relationship.

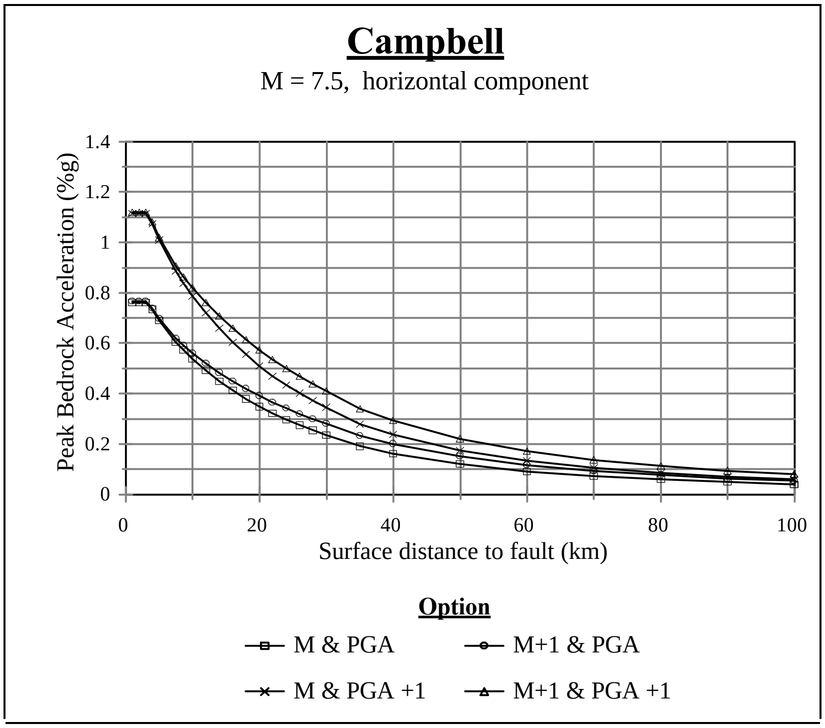

Figure 8. Uncertainty options and Campbell relationship.

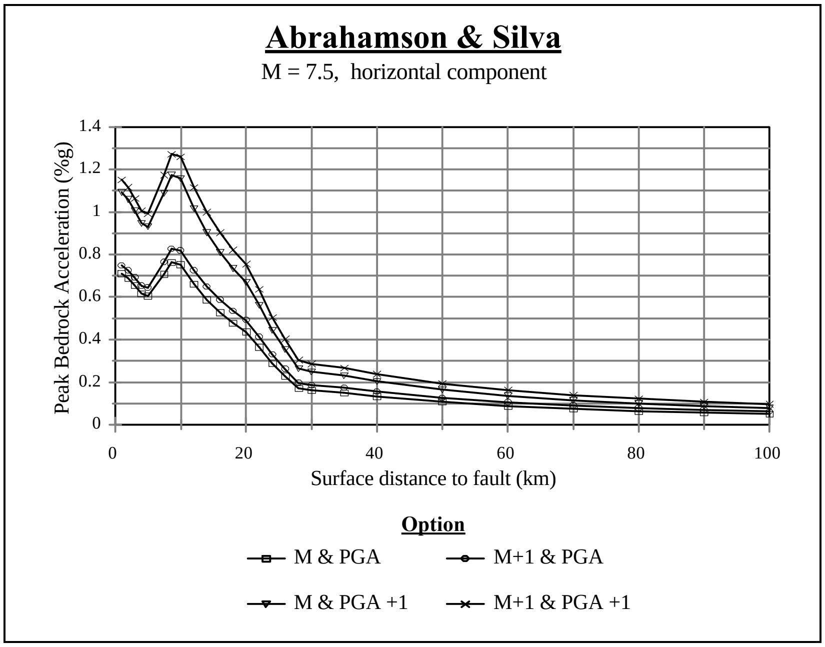

Figure 9. Uncertainty options and Abrahamson and Silva relationahip.

RESULTS

Peak ground accelerations were calculated for each attenuation relationship using Option 3 as described in the previous section. The hanging wall effect is apparent in both the Sea96 and the Abrahamson and Silva relationships as the contours extend farther from the surface rupture trace on the down-dip side of the fault. The Campbell relationship gives nearly symmetric results around each fault.

The Abrahamson and Silva (1997) relationship was selected for the final map production for the following reasons. First, it returns both horizontal and vertical components of PGA. Second, it accounts for increased accelerations on the hanging wall side of normal faults. The Abrahamson and Silva relationship, at the present time, appears to be a good representation of the maximum ground motion in the state of Utah.

Figures 10 and 11 display reduced versions of the maximum peak horizontal and vertical bedrock acceleration maps, respectively, for the state of Utah. ArcView project files of the final two analyses of maximum peak horizontal and vertical bedrock acceleration were copied onto CD-ROM. This format provides added flexibility and utility for those who have access to ArcView and Spatial Analyst. An ArcView user is able to zoom in on a specific location and view the exact values of peak ground acceleration in specific grid cells. Further analysis of a site (or the entire state) is also possible using the grided data sets within the ArcView environment.

The CD that is included with this report contains the files necessary to run an analysis for the full state or for a given region. A demonstration is also included on the CD that shows how the PGA for a site can be determined using a specific geographical area as the study area.

The deterministic results presented on Figures 10 and 11 should be useful in providing an upper limit for comparison to probabilistic results such as those shown in Figure 12. The probabilistic contours are from the National Seismic Hazard Mapping Project (Frankel et al., 1996) for an exceedance probability of 2 percent in 50 years, or an equivalent average recurrence interval of 2,475 years. Comparing the deterministic results in Figure 10 with the probabilistic peak horizontal acceleration values in Figure 12 indicates the deterministic map has larger values than this particular probabilistic map in almost all locations. There are locations where the probabilistic values are higher than the corresponding deterministic values. These locations are generally in locations far from faults. This difference is probably due to the fact that the probabilistic maps have taken into account the background earthquake whereas the deterministic maps have not. Note: Comparisons with different probabilistic maps (different return intervals, different analysis methods) will yield different results.

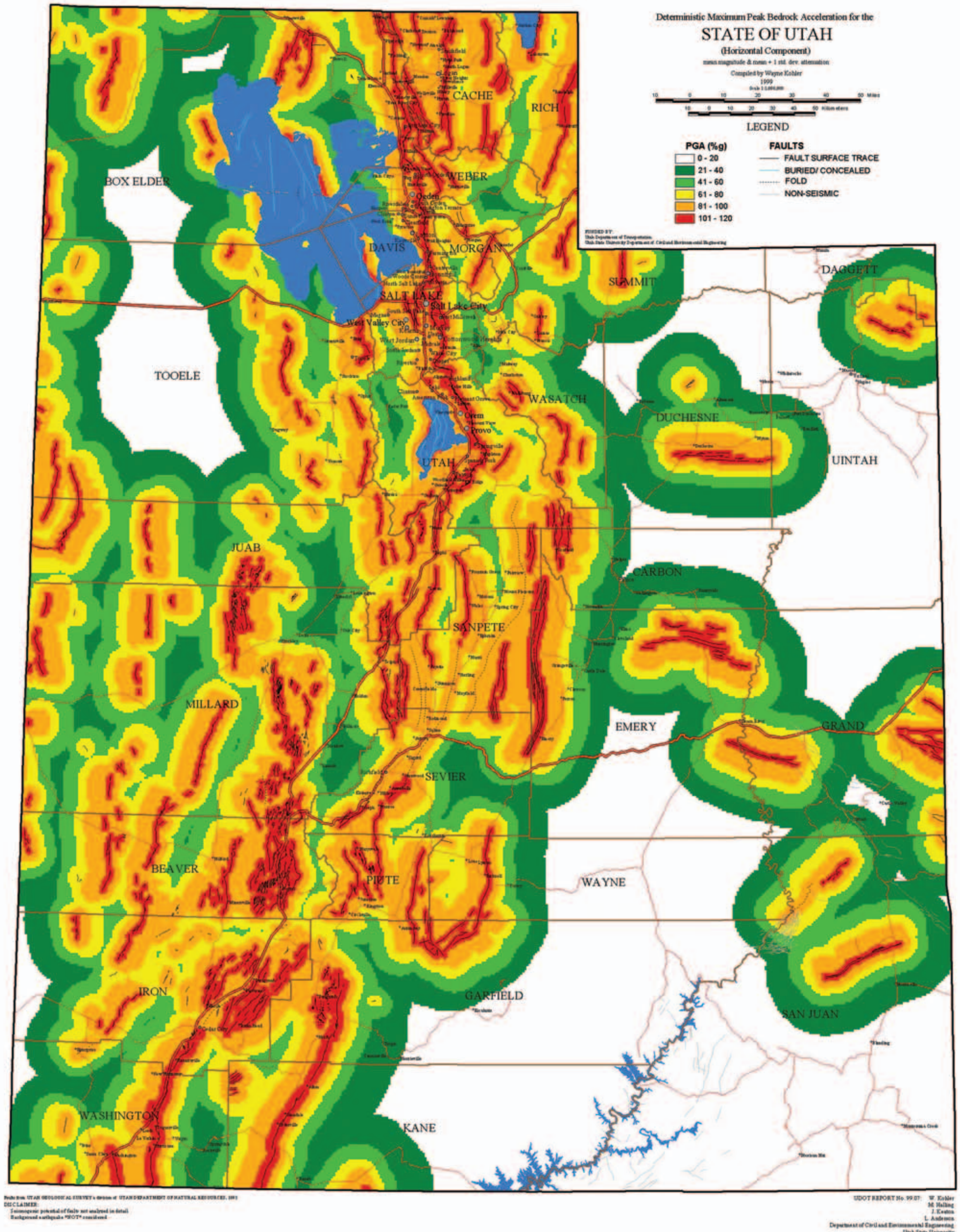

Figure 10. Utah maximum peak horizontal bedrock acceleration.

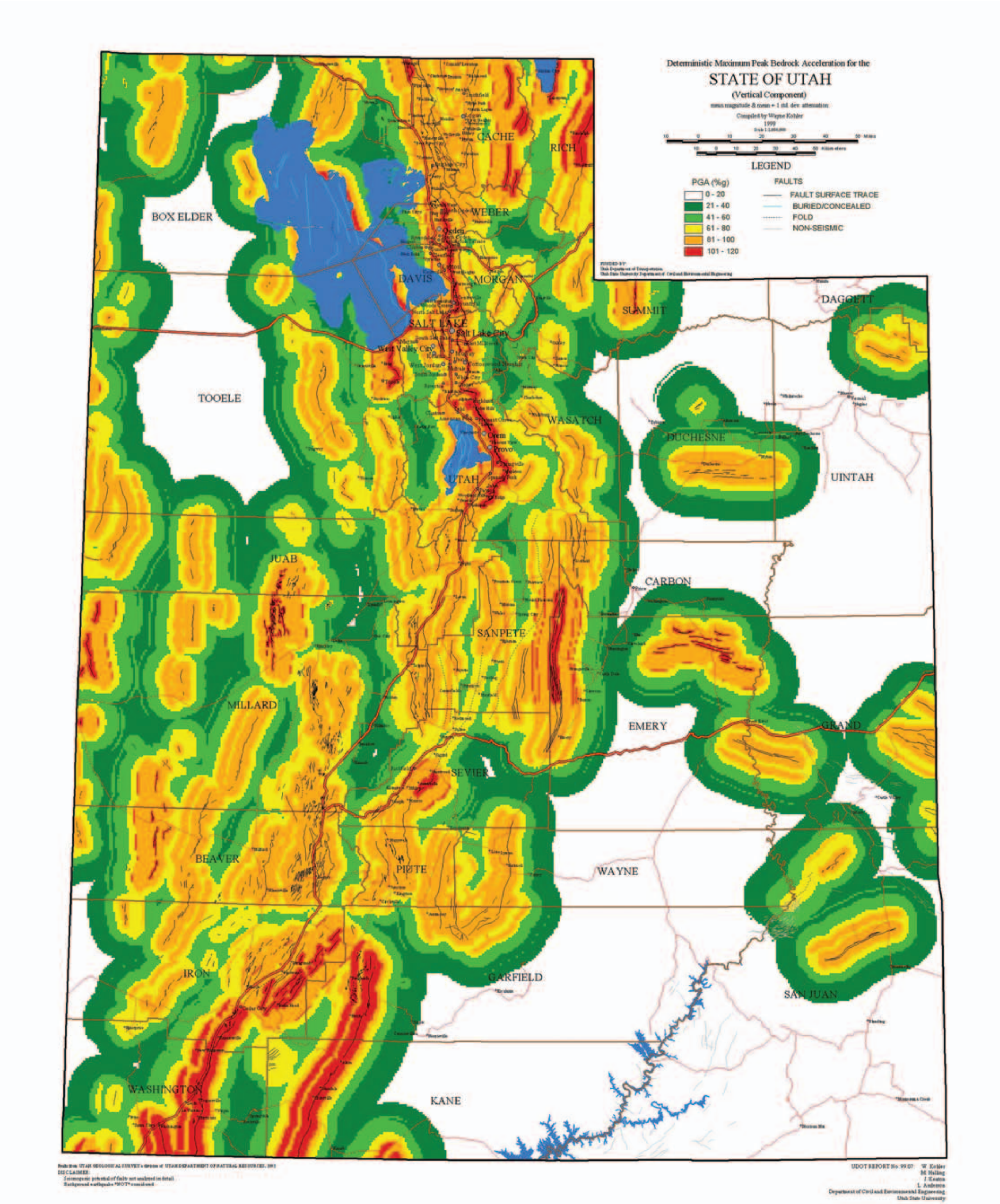

Figure 11. Utah maximum peak vertical bedrock acceleration.

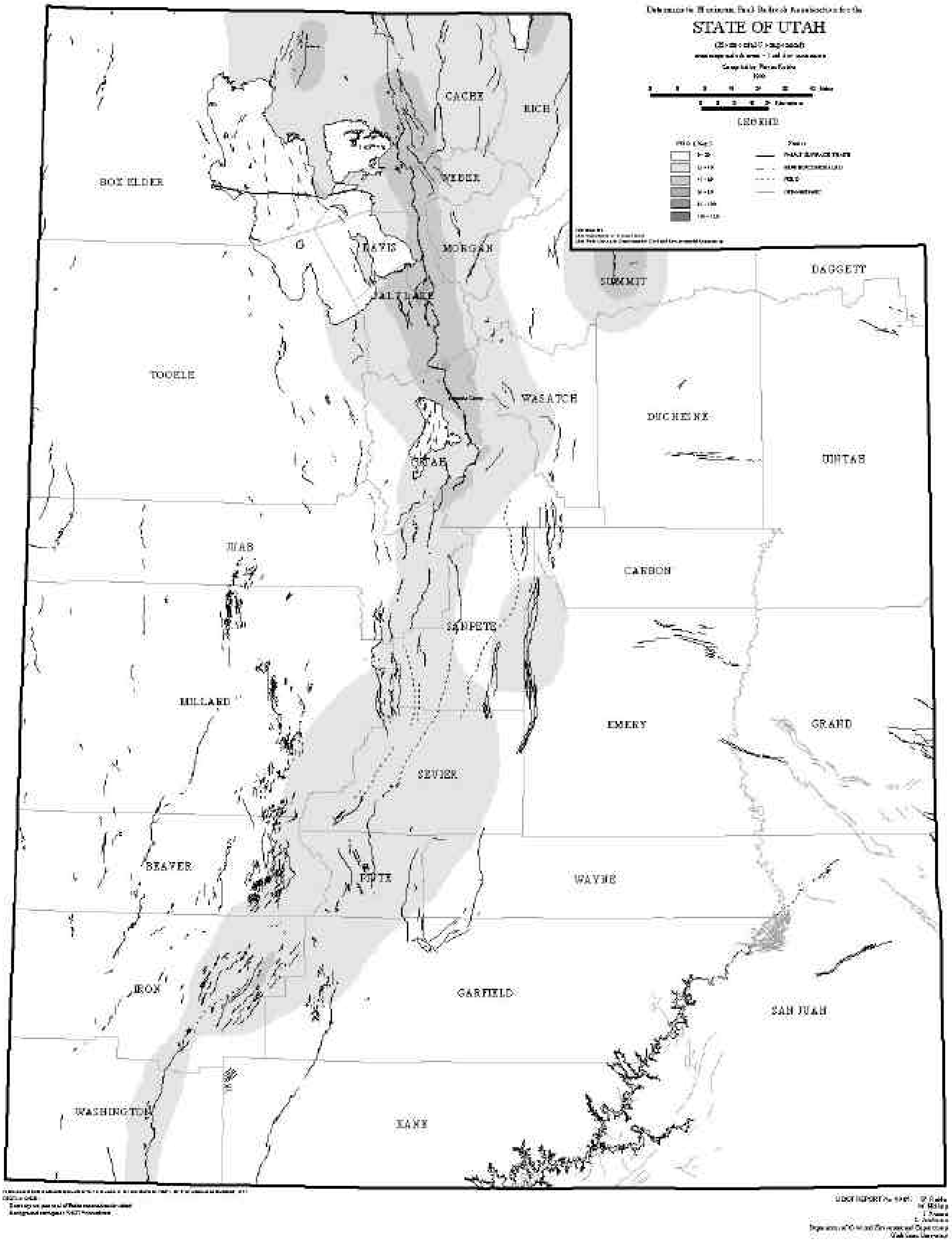

Figure 12. USGS PGA, 2% probability of exceedance in 50 years.

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Appendix A. Fault Parameter Database

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
101		6.68	6.92	ARIZONA	W	1	60	20.1		
102		6.48	6.72	ARIZONA	E	1	60	12.6		
103		7.08	7.34	ARIZONA	NSE	1	60	51.4		
104		7.29	7.57	ARIZONA	SNW	1	60	80.1		
105		6.74	6.98	ARIZONA	E	2	60	22.9		
106		6.63	6.87	ARIZONA	SNE	2	60	17.9		
107		7.30	7.58	ARIZONA	W	1	60	82.3		
108		7.44	7.72	ARIZONA	NW	1	60	108.7		
109		6.36	6.60	ARIZONA	NNW	2	60	9.3		
110		6.70	6.94	ARIZONA	NNE	2	60	20.8		
111		6.89	7.13	ARIZONA	NSW	1	60	32.6		
112		7.12	7.38	ARIZONA	SNE	1	60	55.5		
113		6.86	7.10	ARIZONA	NSW	1	60	30.4		
114		6.65	6.89	ARIZONA	NSW	1	60	18.5		
115		6.88	7.12	ARIZONA	SNW	2	60	31.6		
201		6.98	7.22	NEVADA	SE	1	60	40.2		
202		6.28	6.52	NEVADA	E	1	60	7.9		
203		6.75	6.99	NEVADA	SNW	1	60	23.8		
204		6.77	7.01	NEVADA	W	1	60	24.7		
205		6.81	7.05	NEVADA	NSE	1	60	27.1		
206		7.50	7.78	NEVADA	SNW	1	60	134		
207		6.45	6.69	NEVADA	NSE	1	60	11.7		
208		6.75	6.99	NEVADA	NSE	1	60	23.6		
209		7.20	7.48	NEVADA	W	1	60	67		
210		7.20	7.48	NEVADA	E	1	60	67.6		
211		6.85	7.09	NEVADA	W	1	60	30		
212		6.44	6.68	NEVADA	SNW	1	60	11.4		
213		6.41	6.65	NEVADA	SNW	1	60	10.5		

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
214		7.50	7.78	NEVADA	E	1	60	131.8		
215		7.18	7.46	NEVADA	E	1	60	64.6		
216		7.45	7.73	NEVADA	E	1	60	110		
217		7.37	7.65	NEVADA	W	1	60	94		
218		6.57	6.81	NEVADA	W	1	60	15.2		
219		6.61	6.85	NEVADA	E	1	60	16.7		
220		7.04	7.29	NEVADA	W	1	60	46.5		
221		6.61	6.85	NEVADA	E	1	60	17		
222		6.73	6.97	NEVADA	NSE	2	60	22.5		
223		7.39	7.67	NEVADA	SNW	1	60	98.8		
224		7.11	7.37	NEVADA	SNW	1	60	54.2		
225		7.07	7.33	NEVADA	E	1	60	50.1		
226		6.85	7.09	NEVADA	NSW	2	60	29.6		
227		6.81	7.05	NEVADA	NW	1	60	27		
228		7.01	7.26	NEVADA	NSE	1	60	43.7		
229		6.66	6.90	NEVADA	NSE	2	60	18.8		
230		7.39	7.67	NEVADA	SNW	1	60	97.6		
301		6.77	7.01	IDAHO	NSE	1	60	24.8		
302		6.64	6.88	IDAHO	SNE	2	60	18.2		
303		6.39	6.63	IDAHO	SE	1	60	10		
304		6.77	7.01	IDAHO	SNE	1	60	24.4		
305		6.74	6.98	IDAHO	E	1	60	23.1		
306		6.57	6.81	IDAHO	E	1	60	15.5		
307		6.25	6.49	IDAHO	W	1	60	7.3		
308		6.90	7.14	IDAHO	W	1	60	33.3		
309		6.79	7.03	IDAHO	W	1	60	26.1		
310		6.96	7.20	IDAHO	SNE	1	60	38.3		
311		7.00	7.24	IDAHO	W	1	60	41.9		
312		6.46	6.70	IDAHO	W	1	60	11.9		
313		7.20	7.48	IDAHO	E	1	60	67.1		

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
314		6.47	6.71	IDAHO	E	1	60	12.3		
315		7.19	7.47	IDAHO	SNW	1	60	66.5		
316		6.32	6.56	IDAHO	W	1	60	8.6		
317		6.40	6.64	IDAHO	N	1	60	10.4		
318		6.33	6.57	IDAHO	SNE	1	60	8.7		
319		7.24	7.52	IDAHO	NSW	1	60	73.3		
320		7.14	7.42	IDAHO	E	1	60	59.3		
321		6.75	6.99	IDAHO	SNE	1	60	23.8		
322		6.50	6.74	IDAHO	SNE	2	60	13.2		
323		6.96	7.20	IDAHO	NSW	1	60	38.9		
324		6.96	7.20	IDAHO	SNE	1	60	38.1		
325		7.14	7.42	IDAHO	NSW	1	60	59.1		
326		6.83	7.07	IDAHO	SNE	1	60	28.4		
327		6.95	7.19	IDAHO	SNE	1	60	38		
328		6.81	7.05	IDAHO	E	1	60	26.9		
329		7.20	7.48	IDAHO	NSW	1	60	66.9		
401		7.03	7.28	WYOMING	W	1	60	45.5		
402		6.98	7.23	WYOMING	W	1	60	40.6		
403		6.04	6.28	WYOMING	NSW	1	60	4.4		
404		6.15	6.39	WYOMING	W	1	60	5.8		
405		6.59	6.83	WYOMING	W	1	60	16.2		
406		5.77	6.01	WYOMING	SW	1	60	2.3		
407		6.58	6.82	WYOMING	SNW	1	60	15.8		
408		5.99	6.23	WYOMING	SNW	1	60	4		
601	Hansel Valley - fault	6.90	7.24	UTAH	SE	1	60	13	2.6	1.55
602	North Promontory	7.01	7.34	UTAH	SNW	1	60	26.5	2.5	2.25
603	Hansel Valley - vly flr	6.67	6.91	UTAH	NSE	2	60	19.5		
604	Hansel Mtns.	6.56	6.80	UTAH	NSE	1	60	15		
605	Wasatch - Colliston segment	6.88	7.12	UTAH	W	1	60	32		

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
606	Wasatch - Brigham C. segment	6.94	7.27	UTAH	W	1	60	40	2.5	1.75
607	Big Pass fault	6.64	6.88	UTAH	E	1	60	18		
608	East GSL fault zone	7.40	7.68	UTAH	NSW	1	60	100		
609	Dolphin Island	6.66	6.90	UTAH	NSE	1	60	19		
610	North Promontory Range	6.21	6.45	UTAH	N	1	60	6.6		
611	Pilot Range	7.01	7.26	UTAH*	W	1	60	43.3		
612	Blue Spring Hills	5.80	6.04	UTAH	SNE	1	60	2.5		
613	West Cache Fault - Cache Butte Area	5.71	5.95	UTAH	NE	1	60	2		
614	East Lakeside Mountains	6.94	7.18	UTAH	E	2	60	36.5		
615	West Cache Fault - Clarkston	6.95	7.19	UTAH*	SNE	1	60	37.6		
616	Wasatch - Clarkston Mtn.	7.16	7.43	UTAH*	W	1	60	61.4		
617	Raft River Mtns.	5.87	6.11	UTAH	E	1	60	3		
618	Goose Creek Mtns.	6.09	6.33	UTAH	SNW	2	60	5		
619	Grouse Creek & Dove Mtns.	7.06	7.32	UTAH	NSE	1	60	48.5		
701	Sheeprock fault zone	6.45	6.69	UTAH	SNE	1	60	11.5		
702	Silver Island Mtns. - southeast	6.64	6.97	UTAH	SE	1	60	2		0.6
703	Cedar Valley	5.94	6.18	UTAH	SNW	1	60	3.5		
704	Silver Island Mtns. - west	6.24	6.48	UTAH	NSE	1	60	7		
705	Lakeside Mtns. - west	6.05	6.29	UTAH	NSW	1	60	4.5		
706	Lookout Pass - south	6.20	6.44	UTAH	W	1	60	6.5		
707	Topliff Hill	6.72	6.96	UTAH	W	1	60	22		
708	Deep Creek	6.94	7.18	UTAH	W	1	60	37		
709	Cedar Mtn. - east	6.39	6.63	UTAH	E	1	60	10		
710	Stansbury	7.00	7.24	UTAH	NSW	1	60	42		
711	Clover	6.05	6.29	UTAH	SNE	1	60	4.5		
712	Vernon Hills	6.05	6.29	UTAH	SNE	1	60	4.5		
713	St. John Station	6.09	6.33	UTAH	NSW	2	60	5		
714	Mercur	6.56	6.80	UTAH	NSW	1	60	15		
715	northern Oquirrh	7.16	7.49	UTAH	W	1	60	21.5	4.8	3.85
716	Puddle Valley	6.89	7.22	UTAH	NSE	1	60	6.5	2.3	1.5

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
717	Deep Creek	6.45	6.69	UTAH	SNE	1	60	11.5		
801	Drum Mtns	7.10	7.36	UTAH	E	1	60	53		
802	Desert faults	6.24	6.48	UTAH	E	1	60	7		
803	Cricket Mtns	5.43	5.67	UTAH	E	1	60	1		
804	Crater Bench	6.87	7.11	UTAH	NSE	1	60	31		
805	Clear Lake	6.92	7.16	UTAH	E	1	60	35		
806	Pavant	6.87	7.11	UTAH	W	1	60	31		
807	Sheeprock Mtn (W)	6.24	6.48	UTAH	SW	1	60	7		
808	SW Simpson Mtn	6.39	6.63	UTAH	SW	1	60	10		
809	Swasey Mtn	7.01	7.25	UTAH	E	1	60	43		
810	House RanGe (W)	7.04	7.29	UTAH	W	1	60	46		1.4
811	Foote Range	6.05	6.29	UTAH	E	1	60	4.5		
812	Snake Valley	7.16	7.43	UTAH	E	1	60	61		
813	Lorne Mtn	6.39	6.63	UTAH	S	1	60	10		
814	Deep Creek Range (E)	6.99	7.23	UTAH	NSE	1	60	40.9		
815	Fish Springs	6.98	7.32	UTAH	E	1	60	30	3.3	
816	E. Tintic Mtn (W)	6.91	7.15	UTAH	NSW	1	60	34		
817	Maple Grove	6.56	6.80	UTAH	E	2	60	15		
818	Scipio	6.17	6.41	UTAH	E	1	60	6		
819	Scipio Valley	6.92	7.26	UTAH	SE	1	60	7		
820	Little Valley	6.68	6.92	UTAH	E	2	60	20	2.7	
821	Pavant Range	6.53	6.77	UTAH	E	1	60	14		
822	Sugarville Area	6.09	6.33	UTAH	NW	1	60	5		
901	Cove Creek dome	6.65	6.89	UTAH	SNW	1	60	18.5		
902	Cove Fort	6.75	6.99	UTAH	SNW	1	60	23.3		
903	Beaver Basin - east	6.98	7.31	UTAH	SNW	1	60	34.6	3	2
904	Beaver Basin - Last Chance	6.98	7.29	UTAH	SNW	1	60	40.2	3	1.75
905	Cove Creek dome	6.25	6.50	UTAH ‡	E	2	60	13.4		
906	Sevier Valley	6.92	7.16	UTAH †	E	2	60	35.4		

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
907	Elsinore	6.25	6.50	UTAH ‡	NSE	1	60	30		
908	Joseph Flats area	6.12	6.36	UTAH	SE	1	60	5.4		
909	Dry Wash fault	6.61	6.85	UTAH	SE	1	60	16.9		
910	Tushar Mtns.	6.67	6.91	UTAH †	E	2	60	19.3		
911	Sevier Valley - east	6.29	6.53	UTAH †	E	2	60	8		
912	Black Mtns.	6.29	6.53	UTAH	NW	1	60	7.88		
913	Escalante Desert - north	6.25	6.49	UTAH	NSE	2	60	7.2		
914	Mineral Mtns. - west	6.95	7.19	UTAH	SNW	1	60	37.8		
915	Spry area	6.14	6.38	UTAH	SNE	1	60	5.6		
916	Black Rock area	6.34	6.58	UTAH	W	1	60	8.9		
917	White Sage Flat	6.41	6.65	UTAH	SNW	1	60	10.5		
918	Meadow Hatton area	6.00	6.24	UTAH	SNW	1	60	4		
919	Beaver Ridge	6.55	6.79	UTAH	SNW	1	60	14.5		
920	Tabernacle	6.34	6.58	UTAH	W	1	60	8.9		
921	Pine Valley - south	6.49	6.73	UTAH	E	1	60	12.9		
922	Pine Valley	6.00	6.24	UTAH	E	1	60	4		
923	Little Rough Range	5.90	6.14	UTAH	NE	1	60	3.2		
924	Wah Wah Mtns. - north	6.49	6.73	UTAH	NE	1	60	12.9		
925	Wah Wah Mtns.	7.11	7.38	UTAH	W	1	60	54.7		
926	Wah Wah Valley	5.78	6.02	UTAH	NE	1	60	2.4		
927	San Francisco Mtns.	7.00	7.24	UTAH	SNW	1	60	41.8		
928	Cricket Mtns.	7.00	7.24	UTAH	SNW	1	60	41.8		
929	Mineral Mtns. - northeast	6.55	6.79	UTAH	SNE	1	60	14.5		
930	Buckskin Valley	5.90	6.14	UTAH	NW	1	60	3.2		
931	Fremont Wash	6.14	6.38	UTAH	NNW	2	60	5.6		
932	Annabella graben	7.23	7.56	UTAH	SE	2	60	12.9	5.2	4.9
933	Red Canyon	6.41	6.65	UTAH	SNE	1	60	10.5		
934	Wah Wah Mtns. - south	6.99	7.23	UTAH	NSE	1	60	41		
935	Sevier fault - north	7.00	7.25	UTAH	W	1	60	42.6		
936	Mountain Home Range - west	6.80	7.04	UTAH	W	1	60	26.6		

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
1001	Sevier fault	7.50	7.75	UTAH*	SNW	1	60	152.3		
1002	Kolob Terrace	6.38	6.62	UTAH	NW	2	60	9.7		
1003	Washington Fault	7.50	7.75	UTAH*	W	1	60	123.1		
1004	Washington dome			UTAH		0				
1005	Volcano Mtn.	5.78	6.02	UTAH	NSE	1	60	2.4		
1006	Gunlock fault strike slip	6.29	6.53	UTAH	W	1	60	8		
1007	Hurricane	7.50	7.75	UTAH*	W	1	60	183		
1008	North Hills	6.07	6.31	UTAH	W	1	60	4.8		
1009	Cross Hollow Hills	6.07	6.31	UTAH	W	1	60	4.8		
1010	Enterprise	6.34	6.58	UTAH	NNW	1	60	8.9		
1011	Antelope Range	6.79	7.03	UTAH	NW	1	60	25.8		
1012	Escalante Desert - near Zane	6.00	6.24	UTAH	SSE	1	60	4		
1013	Johns Valley	5.78	6.02	UTAH	SSE	1	60	2.4		
1014	Escalante Desert - east	6.20	6.44	UTAH	SNW	1	60	6.4		
1015	Cedar Valley - west	6.34	6.58	UTAH	E	1	60	8.9		
1016	Cedar Valley - north	6.57	6.81	UTAH	NW	1	60	15.3		
1017	Sevier Valley - hills near Panguitch	6.83	7.07	UTAH	SNW	1	60	28.2		
1018	Enoch graben	6.63	6.87	UTAH	SNW	1	60	17.7		
1019	Red Hills	6.55	6.79	UTAH	NSE	1	60	14.5		
1020	Parowan Valley	6.83	7.07	UTAH	SE	1	60	28.2		
1021	Cedar City - Parowan	6.25	6.50	UTAH ‡	NW	1	60	25		
1022	Paragonah	6.83	7.07	UTAH	NW	1	60	28.2		
1023	Markagunt Plateau	7.13	7.40	UTAH	SE	2	60	57.1		
1024	Sevier Valley - north	6.54	6.88	UTAH	NSE	2	60	6.4	0.8	
1101	East Cache - north	6.90	7.14	UTAH*	SNW	1	60	33.1		
1102	East Cache - central	6.99	7.27	UTAH	W	1	60	44	1.8	1.3
1103	East Cache - south	6.78	7.11	UTAH	W	1	60	24	1.5	1
1104	Crawford Mtns. - west	7.41	7.69	UTAH*	W	1	60	102.4		
1105	Bear Lake - west	6.20	6.44	UTAH	E	1	60	6.4		
1106	Saleratus Creek	6.79	7.03	UTAH	SNW	1	60	25.8		

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
1107	Bear River Range	7.18	7.46	UTAH	W	1	60	64.4		
1108	Bear Lake - east	7.15	7.48	UTAH*	W	1	60	60.43	5.6	3.3
1109	Dayton	6.63	6.87	UTAH	E	1	60	17.7		
1110	Mantua area	6.72	6.96	UTAH	SNE	2	60	21.7		
1111	southeastern Wellsville Mtns.	6.49	6.73	UTAH	NE	1	60	12.9		
1112	James Peak	6.99	7.32	UTAH	NNW	1	60	7.8	2.4	2.1
1113	Broadmouth Canyon	5.82	6.06	UTAH	SNW	1	60	2.6		
1114	Ogden Valley - North Fork	6.75	6.99	UTAH	NE	1	60	23.3		
1115	Ogden Valley - northeast	6.49	6.73	UTAH	SW	1	60	12.9		
1116	Ogden Valley - southwest	6.49	6.73	UTAH	SNE	1	60	12.9		
1117	Morgan - north	6.29	6.53	UTAH †	NSW	1	60	8		
1118	Morgan - central	6.70	7.03	UTAH †	NSW	1	60	16	1	0.75
1119	Morgan - south	5.78	6.02	UTAH †	NSW	1	60	2.4		
1120	Porcupine Mtn.	6.73	6.97	UTAH	W	1	60	22.5		
1121	West Cache Fault - Wellsville	6.76	7.00	UTAH	SNE	1	60	24.1		
1122	Wasatch - Weber segment	7.15	7.43	UTAH	W	1	60	61	3	2
1201	Duschene-Pleasant Vlly	7.04	7.29	UTAH	N	1	60	46		
1202	Towanta Flat graben	6.14	6.38	UTAH	NW	2	60	5.5		
1203	Wasatch - Provo segment	7.22	7.50	UTAH	W	1	60	69.5	3	2.25
1204	Strawberry	6.88	7.13	UTAH	W	1	60	32	1.8	0.95
1205	Stinking Springs	6.41	6.65	UTAH	W	1	60	11		
1206	Wasatch - Salt Lake City	7.11	7.45	UTAH	W	1	60	46	5	3.25
1207	West Valley - Taylorsville	6.86	7.19	UTAH	W	1	60	15.5	1.5	1.35
1208	West Valley - Granger	6.86	7.19	UTAH	NSW	1	60	17	1.5	1.35
1209	Frog Valley	6.09	6.33	UTAH	NSE	1	60	5		
1210	Parley's Peak	6.00	6.24	UTAH	SE	1	60	4		
1211	East Kamas	6.56	6.80	UTAH	W	1	60	15		
1212	Round Valley	6.45	6.69	UTAH	NE	2	60	11.5		
1213	Little Diamond Creek	6.59	6.87	UTAH	SE	1	60	13.5		
1214	Elizabeth Ridge	6.09	6.33	UTAH	NNW	1	60	5		

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
1215	Bald Mtn.	5.80	6.04	UTAH	NSE	1	60	2.5		
1216	East Canyon - north segment	6.55	6.79	UTAH	NSE	1	60	14.5		
1217	East Canyon - south segment (scarp?)	6.46	6.70	UTAH	NSE	1	60	12		
1218	Bear River	7.11	7.45	UTAH*	W	1	60	40	5	3
1219	Utah Lake	6.85	7.09	UTAH	NSE	1	60	30		
1301	Salt Creek area			UTAH		0				
1302	Juab Valley	6.51	6.75	UTAH	E	1	60	13.5		
1303	Long Ridge - west	6.57	6.81	UTAH	W	1	60	15.5		
1304	Long Ridge - northwest	6.71	6.95	UTAH	NW	1	60	21.5		
1305	Joes Valley	6.98	7.31	UTAH †	W	2	60	34	3	2
1306	West Joes Valley fault	7.14	7.48	UTAH †	W	2	60	57.5	5.5	3
1307	East Joes Valley fault	7.13	7.40	UTAH †	W	2	60	57	2	1.25
1308	southern Joes Valley f. zone	6.97	7.21	UTAH	W	2	60	39		
1309	Pleasant Valley - Pleas. Vlly	6.65	6.89	UTAH	W	2	60	18.5		
1310	Pleasant Valley - Dry Valley	6.39	6.63	UTAH	W	2	60	10		
1311	Pleasant Valley - unnamed	6.80	7.04	UTAH	W	2	60	26.5		
1312	Gooseberry	6.74	6.98	UTAH	E	2	60	23		
1313	Snow Lake	6.78	7.02	UTAH	W	2	60	25		
1314	Sage Valley	6.45	6.69	UTAH	NSE	1	60	11.5		
1315	White Mtn. area	6.61	6.85	UTAH	W	2	60	17		
1316	Sanpete-Sevier Valley	6.25	6.50	UTAH ‡	SNW	1	60	70.6		
1317	Redmond Hills	6.25	6.50	UTAH ‡	E	1	60	19		
1318	Gunnison	7.00	7.25	UTAH	E	1	60	42.5		
1319	Price River area	7.09	7.36	UTAH	S	1	60	52.5		
1320	Japanese & Cal Valleys	6.86	7.10	UTAH	E	2	60	30.5		
1321	Wasatch - Nephi segment	7.02	7.30	UTAH	W	1	60	44	2.5	1.95
1322	Wasatch - Levan segment	6.96	7.29	UTAH	SNW	1	60	31	2	1.9
1323	Wasatch - Fayette segment	6.60	6.84	UTAH	W	1	60	16.5		
1324	Big & Water Hollows			UTAH		0				
1325	Wasatch monocline	6.25	6.50	UTAH ‡	SNW	1	60	105.6		

Locnum	Name	Mw	Mw+σ	State	Dip Dir	Dip Model	Dip Angle (°)	Length (km)	Max Disp (m)	Avg Disp (m)
1326	Valley Mtn.	6.25	6.50	UTAH ‡	E	1	60	38.4		
1401	Thousand Lake	7.06	7.32	UTAH	W	1	60	48.5		
1402	Aquarius & Awapa Plateaus	6.14	6.38	UTAH	SSW	1	60	5.5		
1403	Paunsaugunt	7.03	7.28	UTAH	W	1	60	45		
1404	Tenmile	6.92	7.16	UTAH	NNE	2	60	35		
1405	Koosharem	5.80	6.04	UTAH	NSE	1	60	2.5		
1406		6.66	6.90	UTAH	SNE	1	60	19.2		
1407		6.81	7.05	UTAH	NW	2	60	27.1		
1501	Bright Angel			UTAH		0				
1601	Diamond Gulch	6.69	6.93	UTAH	NNE	1	60	20.5		
1602	Pot Creek	6.51	6.75	UTAH	NNE	2	60	13.5		
1801	Salt & Cache Valleys			UTAH		0				
1802	Moab / Spanish Valley			UTAH		0				
1803	Uncompahgre	6.74	6.98	UTAH	SSW	1	60	22.8		
1804	Castle Valley	0.00	0.00	UTAH		0				
1805	Pine Ridge	0.00	0.00	UTAH		0				
1806	Sinbad & Paradox Valleys	6.22	6.46	UTAH	SSW	2	60	6.7		
1807	Fisher Valley			UTAH		0				
1808	Lisbon Valley	0.00	0.00	UTAH		0				
1809	Meander anticline	6.25	6.50	UTAH ‡	SE	2	60	20.1		
1810	Gibson dome anticline			UTAH		0				
1811	Needles			UTAH		0				
1812	Lockhart	6.59	6.83	UTAH	NW	1	60	16		
1901	Shay	6.98	7.22	UTAH	NNW	1	60	40		

* Extends into adjacent state
‡ Fold. Magnitude capped at 6.25. Magnitude + 1 standard deviation capped at 6.5
† Magnitude assigned largest of several segments of same fault

Appendix B. Avenue Scripts

Abrahamson & Silva (1997) Avenue script

```
'This script is used to calculate a grid of peak bedrock acceleration
'values using the Abrahamson and Silva attenuation relationship.
'
'Required:  shape file of fault surface rupture traces
'          and an accompanying table with magnitude, magnitude + 1 standard
'          deviation, dip azimuth, and dip model (double or single dipping)
'          for each fault in the shapefile.
'
'ESRI's Spatial Analyst is required to perform the analysis


'***** Variable initialization
floor = 0
box = Rect.Make(0@0,1@1)
cellSize = 1000
IncludedAng = 90
F = 0
F3 = 1
HW = 1




'***** Find and access table with magnitude, dip azimuth and other data
DocList = av.GetProject.GetDocs
MagTable = MsgBox.List(DocList, "Select Table containing magnitude and other fault data","Select Table")
MagVTab = MagTable.GetVTab
MagSet = MagVTab


FieldList = MagVTab.GetFields
MagField = (MsgBox.List(FieldList, "Select field containing Magnitude data","Set Magnitude Field")).AsString
DipDirField = (MsgBox.List(FieldList, "Select field containing Dip Direction data","Set Dip Direction Field")).AsString
DipAngleField = (MsgBox.List(FieldList, "Select field containing Dip Angle data","Set Dip Angle Field")).AsString
DipModelField = (MsgBox.List(FieldList, "Select field containing Dip Model-type data","Set Dip Model-type Field")).AsString



'***** User prompt:  Calculate horzontal or vertical PGA?
eqoptions = { "Horizontal PGA", "Vertical PGA" }
eqchoice = MsgBox.ListAsString( eqoptions, "Solve for which PGA component?", "PGA Component" )


'***** User prompt:  Add one standard deviation to peak ground acceleration calculations?
ChoiceIsYes = false
sigmachoice = MsgBox.YesNo ("Select 'Yes' to add 1 standard deviation to the Peak Ground Acceleration calculations:", "Add standard
deviation to Peak Ground Acceleration?", ChoiceIsYes)

'***** User prompt:  Set maximum distance (70 km) for calculations?
ChoiceIsYes = false
maxdchoice = MsgBox.YesNo ("Use maximum distance definition (70 km) in calculations?:", "Use maximum distance?", ChoiceIsYes)


'***** Set values for equations:

ChoiceIsYes = true
AcceptDefaults = MsgBox.YesNo("Accept default Values in PGA attenuation relationships?", "Use default values?", ChoiceIsYes)

if (eqchoice = "Horizontal PGA") then

  defaults = {"5.6", "1.640", "0.512", "-1.1450", "-0.144", "0.610", "0.260", "0.370", "-0.417", "-0.230", "0.0000", "0.17", □-0.16", "6.4", "0.03", "2"}

  if (AcceptDefaults = True) then
```

```
      values = defaults
      c4 = values.Get(0).AsNumber
      a1 = values.Get(1).AsNumber
      a2 = values.Get(2).AsNumber
      a3 = values.Get(3).AsNumber
      a4 = values.Get(4).AsNumber
      a5 = values.Get(5).AsNumber
      a6 = values.Get(6).AsNumber
      a9 = values.Get(7).AsNumber
      a10 = values.Get(8).AsNumber
      a11 = values.Get(9).AsNumber
      a12 = values.Get(10).AsNumber
      a13 = values.Get(11).AsNumber
      a14 = values.Get(12).AsNumber
      c1 = values.Get(13).AsNumber
      c5 = values.Get(14).AsNumber
      n = values.Get(15).AsNumber

   else

      labels = { "c4:", "a1:", "a2:", "a3:", "a4:", "a5:", "a6:", "a9:", "a10:", "a11:", "a12:", "a13:", "a14:", "c1:", "c5:", "n:"}
      values = MsgBox.MultiInput( "Enter regressions coefficients or accept defaults for Peak Horizontal Bedrock Acceleration", "Attenuation
regressions coefficients for Abrahamson & Sylva", labels, defaults )

      c4 = values.Get(0).AsNumber
      a1 = values.Get(1).AsNumber
      a2 = values.Get(2).AsNumber
      a3 = values.Get(3).AsNumber
      a4 = values.Get(4).AsNumber
      a5 = values.Get(5).AsNumber
      a6 = values.Get(6).AsNumber
      a9 = values.Get(7).AsNumber
      a10 = values.Get(8).AsNumber
      a11 = values.Get(9).AsNumber
      a12 = values.Get(10).AsNumber
      a13 = values.Get(11).AsNumber
      a14 = values.Get(12).AsNumber
      c1 = values.Get(13).AsNumber
      c5 = values.Get(14).AsNumber
      n = values.Get(15).AsNumber

   end

   defaults = {"0.70", "0.135" }
   if (sigmachoice = true) then
      if (AcceptDefaults = true) then

         values = defaults
         b5 = values.Get(0).AsNumber
         b6 = values.Get(1).AsNumber

      else

         labels = { "b5:", "b6:" }
         values = MsgBox.MultiInput ( "Enter standard deviation coefficients or accept defaults for PGA", "Standard deviation coefficients for
Spudich", labels, defaults )
         b5 = values.Get(0).AsNumber
         b6 = values.Get(1).AsNumber

      end

   end


else

   defaults = {"6.0", "1.642", "0.909", "-1.2520", "0.275", "0.390", "-0.050", "0.630", "-0.140", "-0.220", "0.0000", "0.06", "-0.25", "6.4", "0.03", "3"}

   if (AcceptDefaults = True) then

      values = defaults
      c4 = values.Get(0).AsNumber
      a1 = values.Get(1).AsNumber
      a2 = values.Get(2).AsNumber
```

```
    a3 = values.Get(3).AsNumber
    a4 = values.Get(4).AsNumber
    a5 = values.Get(5).AsNumber
    a6 = values.Get(6).AsNumber
    a9 = values.Get(7).AsNumber
    a10 = values.Get(8).AsNumber
    a11 = values.Get(9).AsNumber
    a12 = values.Get(10).AsNumber
    a13 = values.Get(11).AsNumber
    a14 = values.Get(12).AsNumber
    c1 = values.Get(13).AsNumber
    c5 = values.Get(14).AsNumber
    n = values.Get(15).AsNumber

  else

    labels = { "c4:", "a1:", "a2:", "a3:", "a4:", "a5:", "a6:", "a9:", "a10:", "a11:", "a12:", "a13:", "a14:", "c1:", "c5:", "n:"}
    values = MsgBox.MultiInput( "Enter regressions coefficients or accept defaults for Peak Horizontal Bedrock Acceleration", "Attenuation
regressions coefficients for Abrahamson & Sylva", labels, defaults )

    c4 = values.Get(0).AsNumber
    a1 = values.Get(1).AsNumber
    a2 = values.Get(2).AsNumber
    a3 = values.Get(3).AsNumber
    a4 = values.Get(4).AsNumber
    a5 = values.Get(5).AsNumber
    a6 = values.Get(6).AsNumber
    a9 = values.Get(7).AsNumber
    a10 = values.Get(8).AsNumber
    a11 = values.Get(9).AsNumber
    a12 = values.Get(10).AsNumber
    a13 = values.Get(11).AsNumber
    a14 = values.Get(12).AsNumber
    c1 = values.Get(13).AsNumber
    c5 = values.Get(14).AsNumber
    n = values.Get(15).AsNumber

  end

  defaults = {"0.76", "0.085" }
  if (sigmachoice = true) then
    if (AcceptDefaults = true) then

      values = defaults
      b5 = values.Get(0).AsNumber
      b6 = values.Get(1).AsNumber

    else

      labels = { "b5:", "b6:" }
      values = MsgBox.MultiInput ( "Enter standard deviation coefficients or accept defaults for PGA", "Standard deviation coefficients for
Spudich", labels, defaults )
      b5 = values.Get(0).AsNumber
      b6 = values.Get(1).AsNumber

    end

  end


end


'***** Retrieve selected faults fromt the fault trace shapefile
theView = av.GetActiveDoc
theDisplay = av.GetActiveDoc.GetDisplay
FaultTheme = theView.GetActiveThemes.Get(0)
FaultTheme.EditTable

theTable = av.GetActiveDoc
theVTab = theTable.GetVTab

LocList = List.Make
```

```
'***** Build list of selected faults...
if (theVTab.GetSelection.Count = 0) then
  theSet = theVTab.GetSelection
  theSet.SetAll
else
  theSet = theVTab.GetSelection
end

theField = theTable.GetVTab.FindField("Locnum")

for each rec in theSet
  LocList.Add(theVTab.ReturnValueString(theField, rec))
end

'***** Check fault list for errors, remove duplicates, and sort...

if (LocList.Count > 0) then
  LocList.RemoveDuplicates
  LocList.Sort(true)
else
  return(Nil)
end

nFaults = LocList.Count



'##########################################################################


    '***** obtain analysis extents and cell size if not set
    ae = theView.GetExtension(AnalysisEnvironment)
    if ((ae.GetExtent(box) <> #ANALYSISENV_VALUE) or (ae.GetCellSize(cellSize) <> #ANALYSISENV_VALUE)) then
      ce = AnalysisPropertiesDialog.Show(theView, TRUE, "Output Grid Specification")
      if (ce = NIL) then return NIL end
      theView.SetExtension(ce)
      ce.Activate
    end


'***** Begin anaylsis loop

firsttime = true
for each i in 0..(nFaults-1)

  Locnum = LocList.Get(i)

  '***** build a query string
  LocQuery = "[Locnum] = " + Locnum.AsString

  '***** query fault list and apply selection to the FTheme



  theVTab.Query(LocQuery, theSet, #VTAB_SELTYPE_NEW)
  theVTab.UpdateSelection
  theView.Draw (theDisplay)

  '***** find seismic information for current fault from table
  for each rec in MagVTab
    LocField = MagVTab.FindField ("Locnum")
    Lnum = MagVTab.ReturnValueNumber(LocField, rec).AsString

    if (Lnum = Locnum) then
      theField = MagVTab.FindField(Magfield)
      Mag = MagVTab.ReturnValueNumber(theField, rec)
      theField = MagVTab.FindField(DipDirField)
      Dip = MagVTab.ReturnValue(theField, rec)
      theField = MagVTab.FindField(DipModelField)
      DType = MagVTab.ReturnValue(theField, rec)
      theField = MagVTab.FindField(DipAngleField)
      DAngle = MagVTab.ReturnValue(theField, rec)
```

```
  end

end

if ((DType = 1) or (DType = 2)) then

  '***** Set dip direction parameters from azimuth data

  if (Dip = "N") then
    Azimuth = 0
    ModAzimuth = 270.0
  elseif (Dip = "NNE") then
    Azimuth = 22.5
    ModAzimuth = 247.5
  elseif (Dip = "NE") then
    Azimuth = 45.0
    ModAzimuth = 225.0
  elseif (Dip = "SNE") then
    Azimuth = 67.5
    ModAzimuth = 202.5
  elseif (Dip = "E") then
    Azimuth = 90.0
    ModAzimuth = 180.0
  elseif (Dip = "NSE") then
    Azimuth = 112.5
    ModAzimuth = 157.5
  elseif (Dip = "SE") then
    Azimuth = 135.0
    ModAzimuth = 135.0
  elseif (Dip = "SSE") then
    Azimuth = 157.5
    ModAzimuth = 112.5
  elseif (Dip = "S") then
    Azimuth = 180.0
    ModAzimuth = 90.0
  elseif (Dip = "SSW") then
    Azimuth = 202.5
    ModAzimuth = 67.5
  elseif (Dip = "SW") then
    Azimuth = 225.0
    ModAzimuth = 45.0
  elseif (Dip = "NSW") then
    Azimuth = 247.5
    ModAzimuth = 22.5
  elseif (Dip = "W") then
    Azimuth = 270.0
    ModAzimuth = 0.0
  elseif (Dip = "SNW") then
    Azimuth = 292.5
    ModAzimuth = 337.5
  elseif (Dip = "NW") then
    Azimuth = 315.0
    ModAzimuth = 315.0
  elseif (Dip = "NNW") then
    Azimuth = 337.5
    ModAzimuth = 292.5
  else
    msgbox.error("Error in Dip-dir field.  Values must be in cumpus format. (i.e. N, NNE, etc.)")
  end

  if (Azimuth < 180) then
   Azimuth = Azimuth + 180
  else
   Azimuth = Azimuth -180
  end

  'Set "zero-distance" zone parameters


  ProjFltWidth = 15000/((DAngle*3.1416/180).Tan)
  PerpZoneWidth =   15000/(((90-DAngle)*3.1416/180).Tan) + ProjFltWidth
  StartAng = ModAzimuth - IncludedAng
  EndAng = ModAzimuth + IncludedAng
```

```
'     ###############################################################


'***** convert current fault in FTab to Grid if needed
if (FaultTheme.Is(FTHEME)) then


  '***** obtain analysis extents and cell size if not set
  ae = theView.GetExtension(AnalysisEnvironment)
  if ((ae.GetExtent(box) <> #ANALYSISENV_VALUE) or (ae.GetCellSize(cellSize) <> #ANALYSISENV_VALUE)) then
    ce = AnalysisPropertiesDialog.Show(theView, TRUE, "Output Grid Specification")
    if (ce = NIL) then return NIL end
    theView.SetExtension(ce)
    ce.Activate
  end

  '***** perform Grid conversion
  aPrj = theView.GetProjection
  g = Grid.MakeFromFTab(FaultTheme.GetFTab, aPrj, NIL, NIL)

  '***** check if output is ok
  if (g.HasError) then
    theView.SetExtension(ae)
    ae.Activate
    return NIL
  end

  '***** create zero distance zone
  theNbrHood = NbrHood.MakeWedge(PerpZoneWidth, StartAng, EndAng, true)
  z = g.FocalStats(#GRID_STATYPE_MAX, theNbrHood, false)

  if (z.HasError) then
    return NIL
  end

  '***** create site-to-source distance grid
  r_in = g.EucDistance(NIL, NIL, NIL)
  r_out = z.EucDistance(NIL, NIL, NIL)

  '***** return original analysis environment
  theView.SetExtension(ae)
  ae.Activate

else

  aVTab = FaultTheme.GetGrid.GetVTab
  if (aVTab = NIL) then
    g = FaultTheme.GetGrid
  else
    if (aVTab.GetNumSelRecords > 0) then
      g = FaultTheme.GetGrid.ExtractSelection
    else
      g = FaultTheme.GetGrid
    end
  end

  '***** check if output is ok
  if (g.HasError) then return NIL end

  '***** create zero distance zone
  theNbrHood = NbrHood.MakeWedge(PerpZoneWidth, StartAng, EndAng, true)
  z = g.FocalStats(#GRID_STATYPE_MAX, theNbrHood, false)

  if (z.HasError) then
    return NIL
  end


end

'***** create site-to-source distance grid
r_in = g.EucDistance(NIL, NIL, NIL)
```

```
r_out = z.EucDistance(NIL, NIL, NIL)
asp = r_in.Aspect

'***** Set up correct aspect from dip angle
diff1 = (Azimuth.AsGrid - asp).Abs
diff2 = (diff1 >= 180) * (360.AsGrid - diff1)
diff3 = (diff1 < 180) * 180

diffList = List.Make
diffList.Empty
diffList.Add(diff2)
diffList.Add(diff3)

diffmax = diffList.Get(0)
diffList.Remove(0)

diff4 = diffmax.LocalStats(#GRID_STATYPE_MAX, diffList)

diffList.Empty
diffList.Add(diff1)
diffList.Add(diff4)

diffmin = diffList.Get(0)
diffList.Remove(0)

asp = diffmin.LocalStats(#GRID_STATYPE_MIN, diffList)

diff4 = 90.AsGrid

diffList.Empty
diffList.Add(asp)
diffList.Add(diff4)

diffmin = diffList.Get(0)
diffList.Remove(0)
asp = diffmin.LocalStats(#GRID_STATYPE_MIN, diffList)
depth = (1.AsGrid-((asp.Sqr)/((90.AsGrid).Sqr))) * 15000
dist = (1.AsGrid-((asp.Sqr)/((90.AsGrid).Sqr))) * ProjFltWidth



'***** ???????????????
r = r_in
r_in = r_in * ((DAngle*3.1416/180).Sin) * (r_out < 1)

r_out = r_out > 0
r_out = ((((r - dist).Sqr) + (depth.Sqr)).Sqrt) * r_out

r = r_in + r_out

'***** rename data source
distFN = av.GetProject.GetWorkDir.MakeTmp("dist","")
r.Rename(distFN)

'***** check if output is ok
if (r.HasError) then
  MsgBox.Info("r.HasError = TRUE", "ERROR")
  return NIL
end

'###########################################################


'Create local peak bedrock acceleration grid using SEA96 equations and site-to-source distance grid

r = r/1000
Rrup = ((r.Sqr) + (c4.AsGrid.Sqr)).Sqrt

'***** first calculation

if (Mag < c1) then
  f1 = (a1.AsGrid) + ((a2*(Mag - c1)).AsGrid) + ((a12*((8.5 - Mag)^n)).AsGrid)+ (((a3 + (a13*(Mag - c1))).AsGrid) * (Rrup.Log))
else
  f1 = (a1.AsGrid) + ((a4*(Mag - c1)).AsGrid) + ((a12*((8.5 - Mag)^n)).AsGrid)+ (((a3 + (a13*(Mag - c1))).AsGrid) * (Rrup.Log))
```

```
end

lpga = f1

if (F > 0) then
  if (Mag < 5.8) then
    f3 = a5.AsGrid
  elseif (Mag < c1) then
    f3 = ((a6 - a5)/(c1 - 5.8)).AsGrid
  else
    f3 = a6.AsGrid
  end

  lpga = lpga + (F.AsGrid*f3)
end

If (F3 > 0) then
  lpga = lpga + (a14.AsGrid)
end

if (HW > 0) then
  if (Mag < 5.5) then
    fHW1 = 0
  elseif (Mag < 6.5) then
    fHW1 = Mag - 5.5
  else
    fHW1 = 1
  end


  if (fHW1 > 0) then
    'r1 = r > 4
    fHWa = r <= 8
    fHWb = r > 4
    fHW2 = fHWa*fHWb
    fHW2 = fHW2 * ((a9.AsGrid)*((r - (4.AsGrid))/4))

    fHWa = r <= 18
    fHWb = r > 8
    fHW3 = fHWa*fHWb
    fHW3 = fHW3 * 0.37

    fHWa = r <= 25
    fHWb = r > 18
    fHW4 = fHWa*fHWb
    fHW4 = fHW4 * (a9.AsGrid*(1.AsGrid-((r-18)/7)))


  end
  fHW = (fHW1.AsGrid * (fHW2 + fHW3 + fHW4))*(1.AsGrid-((asp.Sqr)/((90.AsGrid).Sqr)))
  lpga = lpga + fHW
end



'***** If specified above, add standard deviation to pga
if (sigmachoice = true) then
  lpga = lpga
end

'***** final calculation
lpga = lpga.Exp

if (maxdchoice = true) then
  r2 = r <= 70000.AsGrid
  lpga = lpga * r2
end

if (lpga.HasError) then return NIL end

'***** if Dip-type is double (D) then calculate PGA for opposite side


if (DType = 2) then
```

```
firstdouble = true

'***** set dip direction parameter
if (ModAzimuth >= 180) then
   ModAzimuth = ModAzimuth - 180
else
   ModAzimuth = ModAzimuth + 180
end

if (Azimuth >= 180) then
   Azimuth = Azimuth - 180
else
   Azimuth = Azimuth + 180
end



StartAng = ModAzimuth - IncludedAng
EndAng = ModAzimuth + IncludedAng

'*****
theNbrHood = NbrHood.MakeWedge(PerpZoneWidth, StartAng, EndAng, true)
z = g.FocalStats(#GRID_STATYPE_MAX, theNbrHood, false)

if (z.HasError) then
   return NIL
end

'***** create site-to-source distance grid
r_in = g.EucDistance(NIL, NIL, NIL)
r_out = z.EucDistance(NIL, NIL, NIL)
asp = r_in.Aspect

'***** Set up correct aspect from dip angle
diff1 = (Azimuth.AsGrid - asp).Abs
diff2 = (diff1 >= 180) * (360.AsGrid - diff1)
diff3 = (diff1 < 180) * 180

diffList = List.Make
diffList.Empty
diffList.Add(diff2)
diffList.Add(diff3)

diffmax = diffList.Get(0)
diffList.Remove(0)

diff4 = diffmax.LocalStats(#GRID_STATYPE_MAX, diffList)

diffList.Empty
diffList.Add(diff1)
diffList.Add(diff4)

diffmin = diffList.Get(0)
diffList.Remove(0)

asp = diffmin.LocalStats(#GRID_STATYPE_MIN, diffList)

diff4 = 90.AsGrid

diffList.Empty
diffList.Add(asp)
diffList.Add(diff4)

diffmin = diffList.Get(0)
diffList.Remove(0)

asp = diffmin.LocalStats(#GRID_STATYPE_MIN, diffList)
depth = (1.AsGrid-((asp.Sqr)/((90.AsGrid).Sqr))) * 15000
dist = (1.AsGrid-((asp.Sqr)/((90.AsGrid).Sqr))) * ProjFltWidth
```

```
'***** ???????????????
r = r_in
r_in = r_in * ((DAngle*3.1416/180).Sin) * (r_out < 1)

r_out = r_out > 0
r_out = ((((r - dist).Sqr) + (depth.Sqr)).Sqrt) * r_out

r = r_in + r_out

'***** rename data source
distFN = av.GetProject.GetWorkDir.MakeTmp("dist","")
r.Rename(distFN)

'***** check if output is ok
if (r.HasError) then
  MsgBox.Info("r.HasError = TRUE", "ERROR")
  return NIL
end

'###########################################################


'Create local peak bedrock acceleration grid using SEA96 equations and site-to-source distance grid

r = r/1000
Rrup = ((r.Sqr) + (c4.AsGrid.Sqr)).Sqrt

'***** first calculation

if (Mag < c1) then
  f1 = (a1.AsGrid) + ((a2*(Mag - c1)).AsGrid) + ((a12*((8.5 - Mag)^n)).AsGrid)+ (((a3 + (a13*(Mag - c1))).AsGrid) * (Rrup.Log))
else
  f1 = (a1.AsGrid) + ((a4*(Mag - c1)).AsGrid) + ((a12*((8.5 - Mag)^n)).AsGrid)+ (((a3 + (a13*(Mag - c1))).AsGrid) * (Rrup.Log))
end

dpga = f1

if (F > 0) then
  if (Mag < 5.8) then
    f3 = a5.AsGrid
  elseif (Mag < c1) then
    f3 = ((a6 - a5)/(c1 - 5.8)).AsGrid
  else
    f3 = a6.AsGrid
  end

  dpga = dpga + (F.AsGrid*f3)
end

if (F3 > 0) then
  dpga = dpga + (a14.AsGrid)
end

if (HW > 0) then
  if (Mag < 5.5) then
    fHW1 = 0
  elseif (Mag < 6.5) then
    fHW1 = Mag - 5.5
  else
    fHW1 = 1
  end


  if (fHW1 > 0) then
    'r1 = r > 4
    fHWa = r <= 8
    fHWb = r > 4
    fHW2 = fHWa*fHWb
    fHW2 = fHW2 * ((a9.AsGrid)*((r - (4.AsGrid))/4))

    fHWa = r <= 18
    fHWb = r > 8
    fHW3 = fHWa*fHWb
    fHW3 = fHW3 * 0.37
```

```
      fHWa = r <= 25
      fHWb = r > 18
      fHW4 = fHWa*fHWb
      fHW4 = fHW4 * (a9.AsGrid*(1.AsGrid-((r-18)/7)))


    end
    fHW = (fHW1.AsGrid * (fHW2 + fHW3 + fHW4))*(1.AsGrid-((asp.Sqr)/((90.AsGrid).Sqr)))
    dpga = dpga + fHW
  end



  '***** If specified above, add standard deviation to pga
  if (sigmachoice = true) then
    dpga = dpga
  end

  '***** final calculation
  dpga = dpga.Exp

  if (maxdchoice = true) then
    r2 = r <= 70000.AsGrid
    dpga = dpga * r2
  end

  if (dpga.HasError) then return NIL end


  '***** Assemble both sides of double dipping fault
  if (firstdouble) then
    doubleList = List.Make
    firstdouble = false
  end

  doubleList.Empty
  doubleList.Add(lpga)
  doubleList.Add(dpga)

  doubleGrid1 = doubleList.Get(0)
  doubleList.Remove(0)

  '***** Assembled local Peak Bedrock acceleration grid
  lpga = doubleGrid1.LocalStats(#GRID_STATYPE_MAX, doubleList)


end


'  ###########################################################


'***** Create global Peak Bedrock Acceleration Grid and set all points to floor
if (firsttime) then

  gpga = floor.AsGrid
  maxList = List.Make
  firsttime = false

end


'***** Compare local PBA Grid to global PBA grid, set all points to maximum values
maxList.Empty
maxList.Add(gpga)
maxList.Add(lpga)

maxGrid1 = maxList.Get(0)
maxList.Remove(0)

m = maxGrid1.LocalStats(#GRID_STATYPE_MAX, maxList)
name = "Maximum"
pre = "max"
```

```
    gpga = m

    cellFN = av.GetProject.GetWorkDir.MakeTmp(pre,"")
    m.Rename(cellFN)

    if (m.HasError) then
      return NIL
    end

  end

end   '##########   End of analysis loop  ########################


'***** Round global PBA grid up to nearest percent by mult. by 100, truncate decimal, and add 1

if (firsttime) then

  MsgBox.Info( "Selected fault(s) had no Magnitude, Dip-Angle, Dip-Direction, and Dip Model-type data", "Error" )

else
  m = (m*100.AsGrid).Int + 1

  '***** create a theme
  gthm = GTheme.Make(m)

  '***** User prompt: Set name for new PGA theme
  if (eqchoice = "Horizontal PGA") then
    defaultname = "Horiz. PGA %g, (Abrahamson & Silva)"
  else
    defaultname = "Vert. PGA %g, (Abrahamson & Silva)"
  end

  GridName = MsgBox.Input ("Enter a name for the new theme", "New Theme Name", defaultname)

  gthm.SetName(GridName)

  ' add theme to the View
  theView.AddTheme(gthm)

end
```

Appendix C. ArcView Discussions

Much of the following discussions were adapted from ArcView's online help

Grid conversion discussion

When lines are converted to grids, cells are given the value of the line that intersects each cell. When converting polygons, cells are given the value of the polygon found at the center of each cell. Cells that are not intersected by a line are given the value of No Data. When you convert points, cells are given the value of the points found within each cell. Cells that don't contain a point are given the value of No Data. If more than one line or point is found in a cell, then the cell is arbitrarily given the value of one of the lines or points. If this is a problem, use a smaller cell size during conversion. Grid conversion is demonstrated graphically in Figure 14.

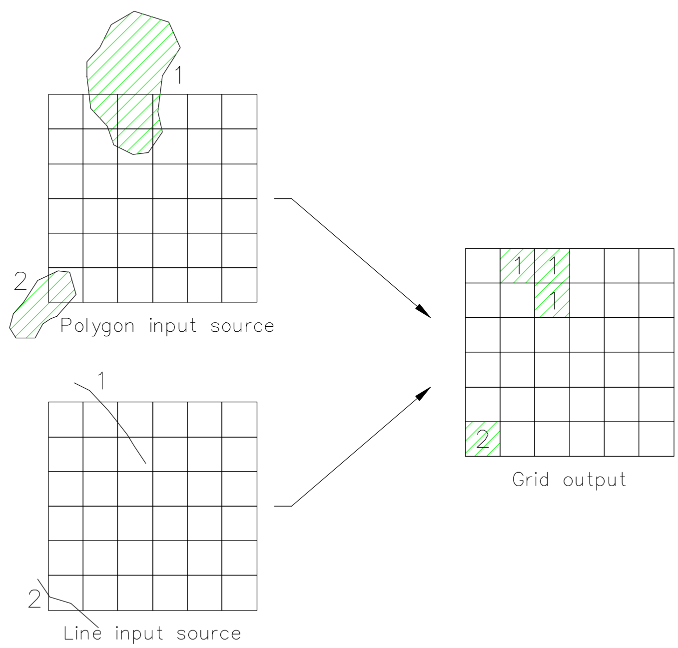

Figure 13. Conversion of vector entities to grid cells

Distance and aspect grid discussion

Several output Grids are potentially available using Avenue requests. These Grids describe each cell's relationship to a source or to a set of source cells. The Euclidean distance Grid identifies the distance from each cell to the closest source cell. The Distance Grid can be derived running the request: aGrid.EucDistance.

Euclidean distance is calculated from the center of the source cell to the center of each of the surrounding cells. True Euclidean distance is calculated in each of the distance functions. Conceptually the Euclidean algorithm works as follows: for each cell, the distance to each source cell is determined by calculating the hypotenuse with the x and y as the other two legs of the triangle. This calculation derives the true Euclidean, rather than the cell distance. The shortest distance to a source is determined, and if it is less than the specified maximum distance, the value is assigned to the cell.

The output values for the Euclidean distance Grid are floating-point distance values. If a cell is at an equal distance from two or more sources, it is assigned to the source that is first encountered in the scanning process (scanning begins at the upper left and moves from left-to-right, top-to-bottom).

The above description is only a conceptual depiction of how values are derived. The actual algorithm computes the information using a two-scan sequential process. Using this process makes the speed of the function independent from the number of source cells, the distribution of the source cells, and the maximum distance specified. The only factor that influences the speed with which the function executes is the size of the grid.

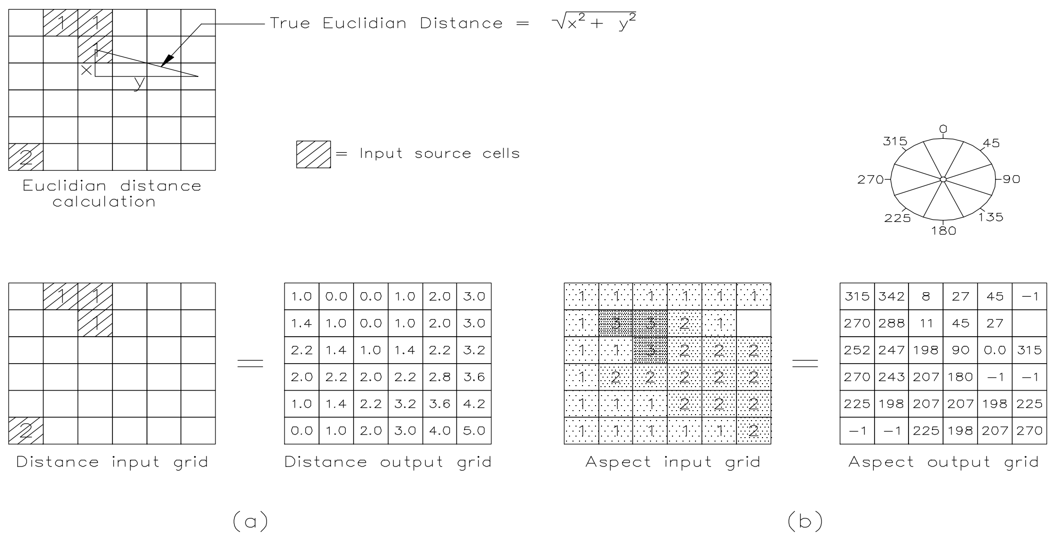

Figure 14. Distance and Aspect grid calculation. (a) Euclidian distance calculation and output grid. (b) Aspect calculation and output grid

In the source Grid, the sources are all of the cells with values other than No Data and all Euclidean functions are calculated from non-source cells assigned No Data. The value 0 is considered a legitimate source. Source cells that are masked with the mask of the Analysis Environment will not be considered in the computations. These cell locations are assigned No Data on the output Grid.

The Aspect request identifies the down-slope direction of the maximum rate of change in value from each cell to its neighbors. Aspect can be thought of as the slope direction. The values of the output Grid are the compass directions of the aspect.

Cells in the input Grid of zero slope (flat) are assigned an aspect of -1. If the center cell in the immediate neighborhood is No Data, the output is No Data. If any neighborhood cells are No Data, they are assigned the value of the center cell when the aspect is computed.

<u>Use in this study</u>

The Distance and Aspect grids were used extensively in this study. After a fault is converted to a grid, then a Distance grid is calculated. The values of the Distance grid are used in calculating the site-to-source distance *r*. The Distance grid is also used as the input grid for the Aspect calculation. The Aspect grid essentially tells what direction a cell is from the fault, and therefore if it is on the hanging-wall side or not. This way values for the hanging wall factor can be added to the appropriate cells on the hanging wall side of the fault in question.

Appendix D. Permission

Date sent: Thu, 01 Oct 1998 13:27:07 -0600
From: grsrc@dpagr1.it.as.ex.state.ut.us (Stuart Challender - AGRC)
Subject: Re: SGID Metadata question?
To: slzzp@cc.usu.edu

Wayne,
There is no copyright on any data classified public in the
State Geographic Information Database (SGID), and no
restrictions. We would ask that you document the source
as the SGID and the agency responsible for developing the
particular layer. That information is available in the SGID
Users Guide or on our home page.

Good luck, let me know if you have other questions,
Stuart Challender
AGRC

> From slzzp@cc.usu.edu Thu Oct 1 12:58:04 1998
> Date: Thu, 01 Oct 1998 13:22:53 +0000
> From: Wayne or Julia Kohler <slzzp@cc.usu.edu>
> Subject: SGID Metadata question?
> To: grsrc@dpagr1.it.as.ex.state.ut.us
> Comments: Authenticated sender is <slzzp@cc.usu.edu>
>
> To whom it may concern,
>
> I am a graduate student at Utah State University. I would like to use the
> information in the fault (glflt) file in my thesis. I would like to know if there is
> any copyright or other restrictions that require written permission to use
> that data (or other SGID data) in my publication.
>
> Thank you.
>
>
> Wayne W. Kohler
>   SLZZP@cc.usu.edu

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