SUMMARY
FOURTH MEETING
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Wednesday & Thursday, February 16 & 17, 2011
Utah Department of Natural Resources Building, Room 2000
1594 West North Temple, Salt Lake City

WELCOME AND INTRODUCTION

Working Group on Utah Earthquake Probabilities (WGUEP) Coordinator Bill Lund called the fourth WGUEP meeting to order at 8:00 a.m. After welcoming remarks and introductions of meeting attendees and visitors (attachment 1), Bill turned the meeting over to Ivan Wong (WGUEP Chairperson) who reviewed the meeting's two-day agenda (attachment 2), and recapped WGUEP progress to date. The meeting then moved into a series of technical presentations and issue discussions.

TECHNICAL PRESENTATIONS

PowerPoint presentations made at the meeting are available at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011A_Presentations.pdf.

Wednesday, February 16

- WGUEP Strawman Logic Tree and WGUEP Products – Ivan Wong
- Recurrence Models – Ivan Wong
- Final Wasatch Fault Central Segment Recurrence Rates – Chris DuRoss
- Final Recurrence Rates for Wasatch Fault End Segments – Mike Hylland
- Methods for Estimating M_{max} – Susan Olig and David Schwartz
- Comparison of Paleoseismic, Seismic, and Geodetic Moment Rates – Christine Puskas
- Moment Rate for Utah and USGS Geodetic Analysis for Utah – Mark Petersen

Thursday, February 17

- Time Dependent Probability Models – Patricia Thomas
- Strawman Rupture Scenarios for the Great Salt Lake Fault – Jim Pechmann
- Background Earthquakes and Consensus Wasatch Front Earthquake Catalog – Walter Arabasz

- Wasatch Front "Other Faults" Model – Bill Lund

ISSUE DISCUSSIONS

Technical presentations and the ensuing discussions they generated are summarized below.

WGUEP Strawman Logic Tree and WGUEP Products

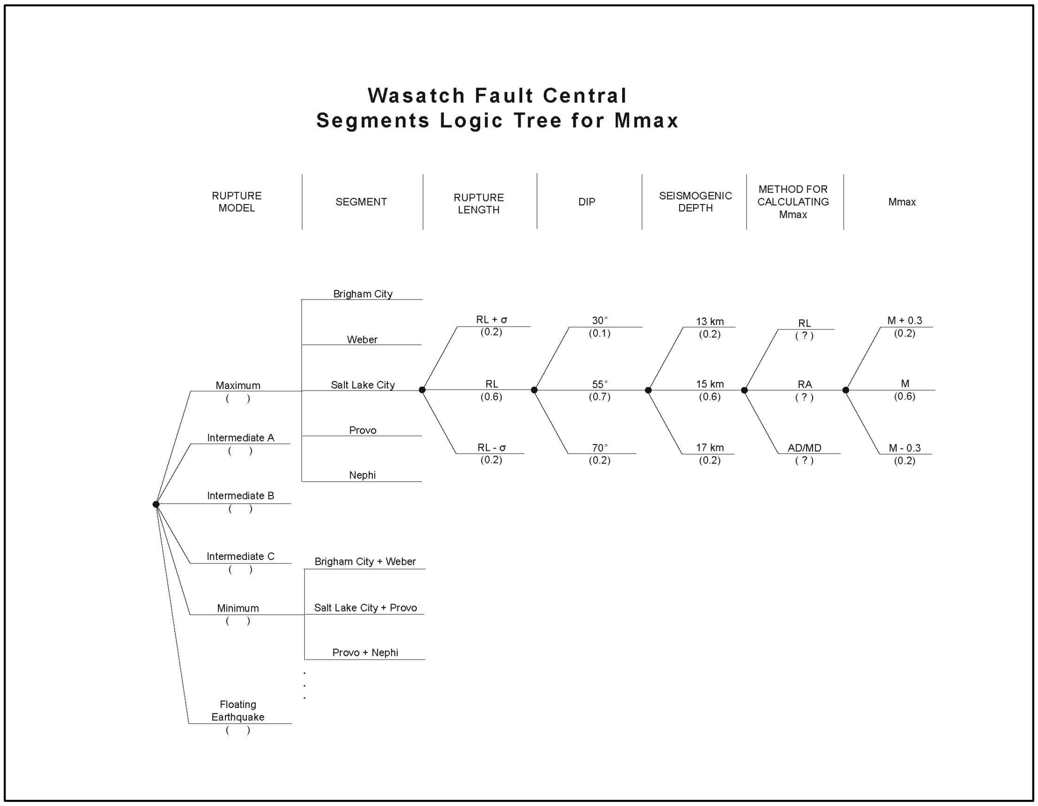
Strawman Logic Tree

Ivan discussed the strawman logic trees (figure 1) prepared at Dave Schwartz's request at WGUEP meeting 3 (December 2010). Ivan noted that the six rupture models developed by the Paleoseismology Subgroup for the five central Wasatch fault zone (WFZ) segments must still have weights assigned to them. He discussed the maximum magnitude and characteristic earthquake recurrence models, and stated that they are best suited to the Working Group's purposes. Ivan then discussed converting recurrence models to activity rates, and stated that for the other faults in the Wasatch Front region, the Working Group needs M_{max} and slip-rate information. Patricia Thomas noted that the recurrence interval node on the original strawman logic tree was in the wrong position and should be moved back to the fourth position on the tree. Figure 1 has a corrected version of the strawman logic tree for probabilities.

Ivan then asked what range of fault dips should be selected for the logic tree; Susan Olig noted that URS Corporation (URS) typically uses a range of 30-55-70 degrees for most normal faults in the Basin and Range Province when performing Probabilistic Seismic Hazard Analyses (PSHAs). Others pointed out that the U.S. Geological Survey (USGS), at the recommendation of the Basin and Range Province Earthquake Working Group (BRPEWG; Lund, 2006), uses 50 ± 10 degrees (40-50-60) for the dip of basin-and-range-style normal faults on the National Seismic Hazard Maps (NSHMs). The Working Group recommended trying both 30-55-70 and 50 ± 10 degrees to see how much difference changing the dip makes to the WGUEP probability calculations. (Note that on the second day of the meeting, the Working Group recommended using 50 ± 15 degrees for the WGUEP "Other Faults" model.)

Segment rupture lengths for the five central WFZ segments and the seismogenic depths to use when calculating M_{max} were the next issues discussed. The Working Group reviewed and accepted the rupture lengths and uncertainty limits at segment boundaries for the five central segments of the WFZ as proposed by the Paleoseismology Subgroup (table 1), and agreed that a range of seismogenic depths of 13-15-17 kilometers is appropriate.

It was noted that the Wasatch Fault Central Segments Logic Tree for M_{max} (figure 1 B) requires a displacement node.



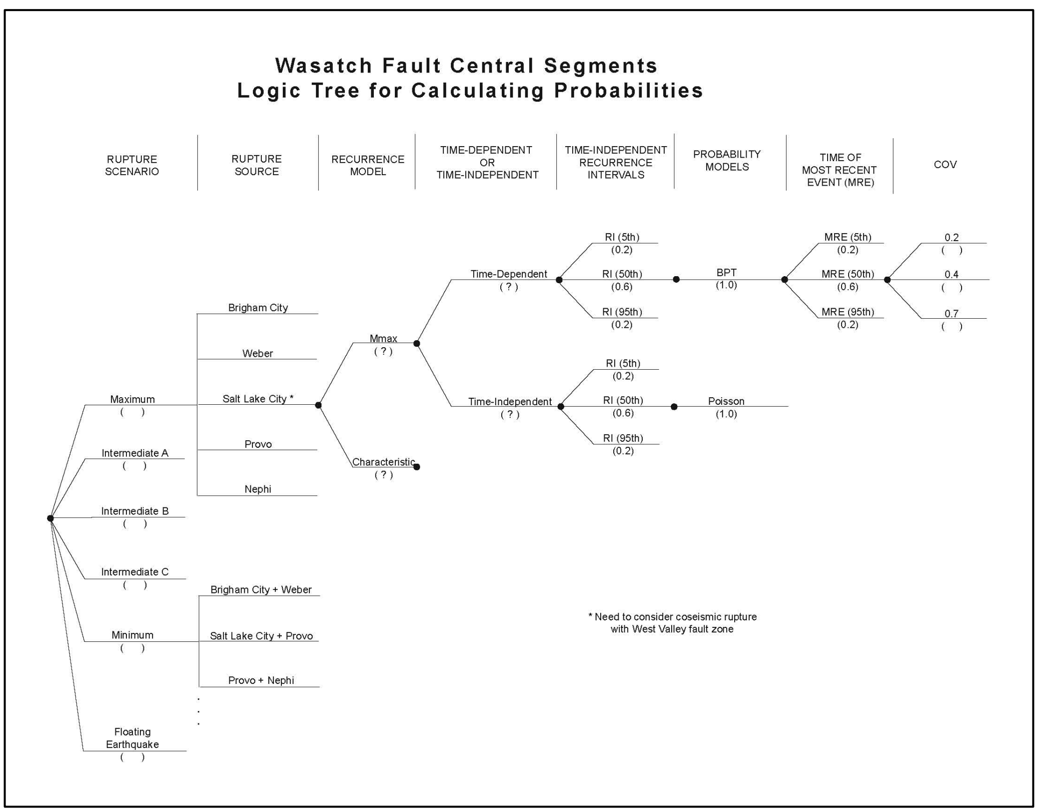


Figure 1. Strawman logic trees (A) for calculating M_{max} and (B) for calculating probabilities.

__Table 1. Summary of segment lengths and segment boundary uncertainty for the five central segments of the Wasatch fault zone.__

Segment	Length[1] (km)	Segment Boundary ± (km)		Rupture Length ± (km)
Brigham City	36	Northern BCS	± 3	± 6
Weber	56	BCS-WS	± 3	± 6.5
Salt Lake City	40	WS-SLCS	± 3.5	± 6.5
Provo	59	SLCS-PS	± 3	± 11.5
Nephi	43	PS-NS	± 8.5	± 11.5
		Southern NS	± 3	
Brigham City + Weber	91[2]	NA		± 6.5
Weber + Salt Lake City	96	NA		± 6
Salt Lake City + Provo	99	NA		± 12
Provo + Nephi	88[2]	NA		± 6

[1]Lengths are straight-line distances measured using fault traces in the UGS/USGS fault and fold database.

[2]Combined segment lengths that are shorter than the lengths of the two segments added directly together reflects over lap at segment boundaries.

Products

Ivan reviewed the currently proposed WGUEP scientific products, which include:

1. Segment-specific time-dependent probabilities for the five central segments of the Wasatch fault zone,

2. Total time-dependent probability for the five central segments of the WFZ,

3. Time-dependent probabilities for the Great Salt Lake fault zone,

4. Fault-specific time-independent probabilities for the five WFZ end segments and other major faults in the Wasatch Front region study area,

5. Total for moderate, but potentially damaging earthquakes below the threshold of surface faulting, and

6. Total time-independent probability for the Wasatch Front region study area.

Discussion next turned to what minimum earthquake magnitude to report in the WGUEP probability estimates; the Working Group decided on a minimum magnitude of 5.0 rather than magnitude 5.5 as previously planned.

Earthquake Recurrence Models

Ivan discussed the three earthquake recurrence models in general use today – characteristic, maximum magnitude, and truncated exponential. In many PSHAs, the three models typically are weighted 0.6 characteristic, 0.3 maximum magnitude, and 0.1 truncated exponential. It was pointed out that in 2005, the BRPEWG recommended that the USGS use two-thirds characteristic and one-third Gutenberg-Richter for the NSHMs.

Discussion centered on which recurrence models to use in the WGUEP process – characteristic and maximum magnitude generally being favored, and on what weights to assign to the models in the logic tree. Lacking consensus, Ivan formed a subgroup consisting of himself, Walter Arabasz, and Jim Pechmann to develop a set of strawman recurrence models and weights for the Working Group's later consideration.

Final Wasatch Fault Central Segment Recurrence Rates

Chris DuRoss reviewed the final earthquake chronology resulting from the Paleoseismology Subgroup's re-evaluation of earthquake timing data available for the five central segments of the WFZ. He also reviewed the process by which the Paleoseismology Subgroup arrived at a set of six strawman earthquake rupture models (minimum, maximum, three intermediate models, and an unsegmented model).

The Working Group then discussed how to assign weights to the six rupture models. Various weighting schemes were considered, but consensus was not achieved. The discussion then turned to the need to sum the moment release per rupture model and compare those values to the moment obtained from long-term segment slip rates. There is also a need to compute and plot magnitude-frequency distributions for the rupture models using magnitude regressions and recurrence rates. Based upon the discussion, it was decided to convene another meeting of the Paleoseismology Subgroup to address these issues and to begin looking at possible methodologies for moment balancing the rupture models.

Final Recurrence Rates for Wasatch Fault End Segments

Mike Hylland reviewed the geologic and paleoseismic constraints on displacement, slip rate, and recurrence for the Wasatch fault end segments (Malad City, Clarkston Mountain, Collinston, Levan, and Fayette); those data are summarized in table 2. The lack of earthquake-specific data generally precludes estimating recurrence for these segments, so modeling will need to use slip-rate data instead.

Table 2. Wasatch fault zone end segments – summary of earthquake parameters.

Segment	MRE Timing	Displacement/ Surface Offset (m)	Time Interval (kyr)	Est. SR (mm/yr)	Recommended SR (mm/yr)	RI (kyr)
Malad City	Late Pleistocene	≤1.5 (est.)	>18	<0.08	0.01–0.1	NA
Clarkston Mountain	Late Pleistocene	2	>18	<0.1	0.01–0.1	NA
Collinston	Late Pleistocene	≤2 (est.) <12	>18 300	<0.1 <0.04	0.01–0.1	NA
Levan	≤1000 cal yr B.P. 1000–1500 cal yr B.P.	1.8 1.8–3.0 4.8	>4.8–9.8 >1.3–3.3 100–250	<0.2–0.4 <0.5–2.3 <0.3±0.1* 0.1–0.6** 0.02–0.05	0.1–0.6	>3 & <12**
Fayette	Early(?) Holocene (SW strand) Latest Pleistocene (SE strand)	0.8–1.6 0.5–1.3 3	<11.5 <18 100–250	>0.07–0.1 >0.03–0.07 0.01–0.03	0.01–0.1	NA

*Hylland and Machette, 2008
** UQFPWG (Lund, 2005)

Mike also reviewed the end segment lengths, and recommended end point uncertainty limits for each of the segments. Segment length and end point uncertainty data are summarized in table 3.

Discussion then focused on whether or not the three northern WFZ segments should be segmented in the WGUEP probability model, or if given their lack of paleoseismic data, it would be better to combine the segments and float a magnitude 6.7-7.0 earthquake along their combined length. Consensus was not reached on this issue.

Table 3. Summary of WFZ end segment lengths and end point uncertainty.

Segment	Length (km)	End Point Uncertainty (km)	Rupture Length Range (km)
Malad City	40	±3	34-46
Clarkston Mountain	19	±3	13-25
Collinston	30	±3	24-36
Levan	32	±3	26-38
	25 (Mapped Holocene rupture)	±3	19-31
	37 (Includes coseismic rupture of subsidiary faults in step over)	±3	31-43
	Length range to consider		19-43
Fayette	22	±3	19-25

A similar discussion was held regarding the two southern WFZ end segments. Because there are marginally better paleoseismic data available for the southern segments, the Working Group decided to incorporate two segmentation models in the probability calculation – one using two segments and the other a single combined segment and a floating earthquake. It was decided to give a weight of 0.5 to each of the models.

Methods for Estimating M_{max}

Susan Olig and David Schwartz (participating via speaker phone) reviewed the various empirical relations available for calculating earthquake maximum magnitudes. At meeting 3 Susan presented a new relation developed by Leonard (2010) for calculating M_{max} for interplate dip-slip faults. Questions regarding Leonard's earthquake data set caused Susan to review the underlying data used to develop the Leonard relation. Susan reported that issues with the earthquake data set are sufficient that she does not recommend using the Leonard (2010) relation for the WGUEP M_{max} calculations. The empirical relations recommended by Susan and David, the fault types (in terms of available paleoseismic data) to which the relations should be applied, and weights recommended for each relation in the WGUEP probability calculations are summarized below.

Empirical Relations for WGUEP Probability Model:

- Wells and Coppersmith (1994) – all fault types
  - Area (A); $M = 4.07 + (0.98 \times \log A)$; $\sigma = 0.24$
  - Surface rupture length (L); $M = 5.08 + (1.16 \times \log L)$; $\sigma = 0.28$

  - Average slip (AD); $M = 6.93 + (0.82 \log AD)$; $\sigma = 0.39$

- Hemphill-Haley and Weldon (1999)
  - AD (from trench sites) and MVCDS, which is a mode value statistic based on n and the percent of fault length that the n samples cover; $M = 6.93 + 0.82 \log (AD \times MVCDS)$

- Hanks and Kanamori (1979)
  - Seismic moment (M_O); $M = (2/3 \times \log M_O) - 10.7$

Fault Categories:

A. Well-mapped with 3 or more trench sites
(segmented with alternative rupture models; have D data)

B. Well-mapped with 1 or 2 trench sites
(may or may not be segmented; have minimal D data)

C. Mapped and no trench sites
(likely not segmented; no D data)

Use different empirical relations (and uncertainties) according to available data and rupture models.

Application of Empirical Relations and Recommended Weights:

- For category A faults use:
  - Wells and Coppersmith – A (0.25)
  - Wells and Coppersmith – L (0.25)
  - Hemphill-Haley and Weldon – AD (0.25)
  - Hanks and Kanamori – M_O (0.25)

- For category B faults use (with $\pm 1\ \sigma$ depending on epistemic uncertainty):
  - Wells and Coppersmith – A (0.3)
  - Wells and Coppersmith – L (0.3)
  - Hanks and Kanamori – M_O (0.2)
  - Wells and Coppersmith – AD (0.2)

- For category C faults use (with $\pm 1\ \sigma$):
  - Wells and Coppersmith – L (0.5)
  - Wells and Coppersmith – A (0.5)

- Truncate all distributions at M 7.8 maximum. Use aleatory uncertainty of $\pm$ 0.12. Review resulting distributions and adjust as needed.

My notes taken at the time of Susan's presentation don't specifically indicate that the Working Group reached consensus on Susan and Dave's recommendations. However, in a later discussion on a different topic, it was stated that the Working Group had approved the above methodology.

Comparison of Paleoseismic, Seismic, and Geodetic Moment Rates

Christine Puskas provided a comparison of moment rates from global positioning systems (GPS), historic earthquakes, and paleoearthquakes in the Wasatch Front region. She reviewed the 2007-2010 Wasatch Region GPS velocities, and showed that the western United States GPS data describe a clockwise rotating velocity field that places the Basin and Range Province (including the Wasatch Front) in extension. She noted the locally high deformation rates recorded across the WFZ.

The Wasatch GPS monitoring network consists of 68 permanent GPS stations operated by the University of Utah and the National Science Foundation/UNAVCO Plate Boundary Observatory. The GPS stations are deployed in three profiles (north, central, south) across the WFZ, and measure contemporary horizontal deformation. GPS monitoring in the Wasatch Front region has been ongoing since 1996, the results show that velocities increase rapidly across the Wasatch Front region, an area that includes multiple basin-and-range-style faults (WFZ, East Cache, Great Salt Lake/Oquirrh, Hansel Valley, and Scipio/Little Valley faults, etc). One type of GPS modeling assumes a locked fault in an elastic seismogenic layer over a creeping fault in a lower crustal layer. With this type of model, the data from the three GPS profiles more closely resemble modeled velocity rates from low dip ($< 40^o$) creeping dislocation.

Christine used Kostrov's formula (Ward, 1998) to estimate the geodetic loading rate. The moment available for earthquakes depends on seismogenic volume (network area • maximum earthquake depth) and strain (deformation rate) for the area. Converting strain rates to moment rates reflects the deformation rate. Geodetic loading rates are 10^{23} to 10^{24} dyne-cm/yr in 0.2^o grid areas established across the Wasatch Front. The greatest loading is taking place along the south-central part of the WFZ. The profile moment rates from interpolated strain rates for the three Wasatch Region GPS profiles are shown in table 4.

Table 4. Moment rates along Wasatch Front GPS profiles.

Area	**Moment Rate (dyne-cm/yr)**
Northern GPS profile	6.7E+24
Central GPS profile	9.1E+24
Southern GPS profile	1.1E+25

The 1981-2011 earthquake record for the Wasatch Front consists of >40,000 earthquakes in the University of Utah Seismograph Stations (UUSS) earthquake catalog. The catalog contains both local and coda magnitudes. The WFZ is quiescent for magnitudes ≥ 3. Using the empirical relation of Bott and others (1977), Christine converted magnitude to seismic moment, and obtained an average seismic moment release rate for the Wasatch Front region of 8.6E+22 dyne-cm/yr – two to three orders of magnitude less than the moment rates calculated from GPS data.

Christine next considered the earthquake history of the five central segments of the WFZ. She obtained moment magnitudes for late Quaternary paleoearthquakes using the earthquake chronology developed by the Paleoseismology Subgroup and the Wells and Coppersmith (1994) moment magnitude surface rupture length (SRL) relation ($M=5.08+1.16 \cdot \log[SRL]$). She then considered the five scenario earthquake rupture models for the central WFZ developed by the Paleoseismology Subgroup, and noted that multisegment earthquakes release more moment, significant uncertainties remain in timing and magnitude, and that timing and magnitude data present no clear patterns. Using moment magnitudes, she then calculated moment rates for the five rupture models (table 5). Table 5 also includes the moment rates determined from GPS data and the historic earthquake catalog for comparison purposes. The moment rates for the rupture models are for the five central segments of the Wasatch fault zone only. Therefore, rates determined for the north/central/southern portions of the rupture models will be less than both the GPS models as a whole and also the rupture models as a whole (see table 5).

Table 5. Moment rate comparison for paleoearthquakes, GPS data, and historical earthquakes for the Wasatch fault zone/Wasatch Front Region.

Source		Moment Rate (dyne cm/yr)	North	Central	South
Paleo-Earthquakes[1]	Minimum rupture model	1.9E+24	1.0E+24	1.3E+24	1.0E+24
	Maximum rupture model	1.5E+24	2.9E+23	2.9E+23	2.9E+23
	Intermediate model A	1.7E+24	7.2E+23	5.6E+23	2.9E+23
	Intermediate model B	1.6E+24	7.2E+23	2.9E+23	4.5E+23
	Intermediate model C	1.6E+24	7.2E+23	2.9E+23	2.9E+23
GPS[2]	Northern GPS profile	6.7E+24			
	Central GPS profile	9.1E+24			
	Southern GPS profile	1.1E+25			
Historical Earthquakes[2]	1981-2011 historic earthquake catalog	8.6E+22			

[1]Five central segments of the WFZ only.

[2]GPS profiles and the region encompassing the historical earthquakes used for this analysis both include additional large basin-and-range faults.

The paleoearthquake rupture model and GPS-derived moment rates disagree by one order of magnitude. Possible reasons that Christine suggested for the discrepancy include:

- Problems with M-SLR relation for paleoearthquakes and/or other parameters to derive paleoseismic moment?
- Over estimate of the GPS network area?
- Not all accumulated moment is released in earthquakes?
- Some elastic strain recovered during earthquakes?
- Ongoing aseismic deformation?
- Time-varying loading rate?

- Loading on other large, nearby faults?

- More/bigger multisegment ruptures?

In her summary, Christine pointed out that GPS data have the advantage of measuring contemporary deformation and provide good spatial and time coverage of more than just the WFZ. However, it is not presently possible to resolve GPS measured strain to individual faults within the Wasatch Front region, and so remains only a measure of overall strains across the region. In Christine's opinion, it is unlikely that GPS and paleoseismic rates will ever match due to uncertainties in moment rate calculations, nonuniform fault loading rates, and other as yet unknown factors that may affect the rates.

In the subsequent discussion, Jim Pechmann questioned Christine's results because other comparisons between paleoseismic and GPS-derived moment rates using similar techniques have found much smaller disagreements.

Moment Rate for Utah and USGS Geodetic Analysis for Utah

Mark Petersen discussed the methodology used by the USGS to calculate seismic moment and moment rate.

Parameters to Calculate Moment/Moment Rate

1. Moment = rigidity * area * displacement
2. Moment rate = rigidity * area * slip rate
3. Slip rate = Moment rate / (rigidity * area)
4. Kostrov's formula converts strain rate to moment rate:
   Moment rate~rigidity * length * width * depth * strain rate (dependent on fault geometry)

USGS assumes a 3X 10^10 N/m^2 rigidity constant
M_0=10**(1.5*M+9.05) N-m
Lengths (l) are based on WFZ segmentation model

For the NSHMs, the USGS assumes a 15 km vertical depth and a planar fault; however, other models are possible:

1. 50 degree dip (0.6 wt) –> 19.6 km down-dip width
2. 60 degree dip (0.2 wt) –> 17.3 km down-dip width
3. 40 degree dip (0.2 wt) –> 23.3 km down-dip width

WFZ segment lengths and magnitudes used by the USGS are shown in table 6. A question was raised regarding the segment lengths reported in table 6; they are longer than the end-to-end lengths typically used in SRL moment magnitude calculations for the WFZ. Mark said he would look into that issue.

Table 6. USGS WFZ segment lengths and magnitudes.

Segment	Length (km)	USGS Assigned Magnitude (M)	Calculated Magnitude (M)
All	305	7.4	7.97
Brigham City	41	6.9	6.95
Weber	63	7.2	7.17
Salt Lake City	48	7.0	7.04
Provo	77	7.4	7.27
Nephi	44	7.0	7.02
Levan	32	6.8	6.84

Mark then presented examples of moment calculations for (A) characteristic earthquakes on the six central WFZ segments and (B) floating and Gutenberg – Richter earthquakes on the WFZ (tables 7 and 8).

Table 7. USGS moment calculations for WFZ segment characteristic earthquakes.

Segment	M	wt(M)	MoRate	Rate*10**-4	Length		Moment Ratet*Wt	Moment (eq)	Moment Rate	50deg SR	60degSR	40degSR
Provo	7.4	0.6	5.93	4.2	77		3.56E+16	1.41E+20	5.93E+16	1.31	1.48	1.10
	7.2	0.2	2.97	4.2			5.95E+15	7.08E+19	2.97E+16	0.66	0.74	0.55
	7.6	0.2	11.8	4.2			2.37E+16	2.82E+20	1.18E+17	2.61	2.96	2.20
Nephi	7	0.6	1.42	4	44		8.52E+15	3.55E+19	1.42E+16	0.55	0.62	0.46
	6.8	0.2	0.71	4			1.42E+15	1.78E+19	7.11E+15	0.27	0.31	0.23
	7.2	0.2	2.83	4			5.66E+15	7.08E+19	2.83E+16	1.09	0.71	0.92
Levan	6.8	0.6	0.42	2.37	32		2.53E+15	1.78E+19	4.21E+15	0.22	0.25	0.19
	6.6	0.2	0.21	2.37			4.22E+14	8.91E+18	2.11E+15	0.11	0.13	0.09
	7	0.2	0.84	2.37			1.68E+15	3.55E+19	8.41E+15	0.45	0.51	0.38
Brigham City	6.9	0.6	1.93	7.7	41		1.16E+16	2.51E+19	1.93E+16	0.80	0.91	0.67
	6.7	0.2	0.97	7.7			1.94E+15	1.26E+19	9.69E+15	0.40	0.46	0.34
	7.1	0.2	3.86	7.7			7.72E+15	5.01E+19	3.86E+16	1.60	1.81	1.35
Weber	7.2	0.6	5.03	7.1	63		3.02E+16	7.08E+19	5.03E+16	1.36	1.54	1.14
	7	0.2	2.52	7.1			5.04E+15	3.55E+19	2.52E+16	0.68	0.77	0.57
	7.4	0.2	10.03	7.1			2.01E+16	1.41E+20	1.00E+17	2.71	3.07	2.28
Salt Lake City	7	0.6	2.73	7.7	48		1.64E+16	3.55E+19	2.73E+16	0.97	1.10	0.81
	7.2	0.2	5.45	7.7			1.09E+16	7.08E+19	5.45E+16	1.93	2.19	1.62
	6.8	0.2	1.37	7.7			2.74E+15	1.78E+19	1.37E+16	0.49	0.55	0.41
						SUM	1.92E+17					

Table 8. USGS moment calculations for WFZ floating and Gutenberg-Richter earthquakes.

Float 7.4 (10% weight-1.2 mm/yr slip rate)	**Dip**	**wt(dip)**	**MoRate**	**Rate*10**-3**		**Wasatch floating large-eq (7.4+-) branches**	**Weighted Moment Rate**	**Moment of M7.4**	**Moment Rate**	**50 degree downdip slip rate**	**60 degree downdip slip rate**	**40 degree downdip slip rate**
7.4	50	0.6	28.16	2	305	19.6	1.70E+17	1.41E+20	2.83E+17	1.58	1.78	1.33
	40	0.2	42.77	3.03	305	23.3	8.56E+16	1.41E+20	4.28E+17	2.39	2.70	2.01
	60	0.2	15.5	1.1	305	17.3	3.11E+16	1.41E+20	1.55E+17	0.87	0.98	0.73
						SUM	2.86E+17					
Gutenberg-Richter (18% weight, M 5-Max mag)	**Dip**	**wt(dip)**	**MoRate**	**Downdip SR**	**Vert SR**	**Horiz SR**	**Weighted Moment Rate**	**RI (yrs)**				
Provo	50	0.6	7.1	1.57	1.2	1	4.26E+16					
	40	0.2	10.08	1.87	1.2	1.4	2.02E+16					
	60	0.2	5.55	1.39	1.2	7	1.11E+16					
Nephi	50	0.6	3.92	1.44	1.1	0.9	2.35E+16					
	40	0.2	5.57	1.71	1.1	1.3	1.11E+16					
	60	0.2	3.07	1.27	1.1	0.6	6.14E+15					
Levan	50	0.6	0.75	0.39	0.3	0.25	4.50E+15					
	40	0.2	1.06	0.47	0.3	0.36	2.12E+15					
	60	0.2	0.58	0.35	0.3	0.17	1.16E+15					
Brigham City	50	0.6	4.38	1.83	1.4	1.2	2.63E+16					
	40	0.2	6.22	2.18	1.4	1.7	1.24E+16					
	60	0.2	3.42	1.62	1.4	0.8	6.84E+15					
Weber	50	0.6	5.76	1.57	1.2	1	3.46E+16					
	40	0.2	8.18	1.87	1.2	1.4	1.64E+16					
	60	0.2	4.51	1.39	1.2	0.7	9.02E+15					
Salt Lake City	50	0.6	4.45	1.57	1.2	1	2.67E+16	262				
	40	0.2	6.32	1.87	1.2	1.4	1.26E+16	185				
	60	0.2	3.48	1.39	1.2	0.7	6.96E+15	337				
						WT SUM	2.74E+17					
									M7.4	M 7		
						TOTAL M	2.16E+17		653 yrs	164 yrs		

Finally, Mark presented a comparison of down-dip slip rates for the six central WFZ segments.

Table 9. USGS determined down-dip slip rates for the six central segments of the WFZ.

Segment	**Geologic slip rate (mm/yr +/- 15%)**	**RI based slip rate (mm/yr +/- 15%)**	**Geodetic slip rate (Zeng)**	**Geodetic slip rate (Chang and Smith)**
Brigham City	1.83	0.80	2.2	5-12
Weber	1.57	1.36	2.6	5-12
Salt Lake City	1.57	0.97	4.1	5-12
Provo	1.57	1.31	4.3	5-12
Nephi	1.44	0.55	4.3	5-12
Levan	0.39	0.22	3.3	5-12

Mark also discussed the current status of the USGS geodetic analysis for Utah. The presentation was identical to that presented at WGUEP meeting 3 (see minutes for meeting 3 at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2010C_Summary.pdf.).

Time Dependent Probability Models

Patricia Thomas briefly reviewed the components (fault model, deformation model, earthquake-rate model, probability model) of the Working Group on California Earthquake Probabilities (WGCEP) (2003) and the Uniform California Earthquake Rupture Forecast 2 (UCERF2) methodologies. She then discussed the probability models used in the WGCEP (2003) forecasts (Poisson, Empirical, Lognormal, Brownian Passage Time, Time Predictable), with particular emphasis on the time-dependent models (Lognormal, Brownian Passage Time, Time Predictable). Patricia then discussed the inconsistencies between multi-segment rates implied by a Brownian Passage Time distribution and actual segment rates produced by a multisegment rupture model that surfaced during the WGCEP (2003) process. Final segment probabilities aggregated from the rupture source were not the same as the Brownian Passage Time computed probabilities because the probability of a segment rupturing and taking a neighboring segment with it has nothing to do with when the segment last ruptured. The problem increased with an increasing number of segments.

Patricia concluded with a quote from Field and Gupta (2008), "WGCEP (2003) methodology remains the best available science," and consequently was adopted for UCERF2.

Strawman Rupture Scenarios for the Great Salt Lake Fault

As a follow up to his presentation at WGUEP meeting 3 on "Should the WGUEP Compute Time-Dependent Probabilities for Large Earthquakes on the Great Salt Lake Fault" (see http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2010C_Summary.pdf and http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011A_Presentations.pdf [page 169]), Jim discussed factors favoring single and multisegment ruptures of the Great Salt Lake fault, and presented six strawman rupture scenarios with possible weights (table 10). The Working Group discussed the scenarios and recommended preferred consensus weights (table 10).

Table 10. Proposed Great Salt Lake fault zone rupture scenarios and recommended weights.

Rupture Scenarios				WS1	WS2	WGUEP
R	P	FI	AI	0.75	0.68	0.75
R+P		FI	AI	0.05	0.08	0.00
R	P+FI		AI	0.00	0.00	0.00
R	P	FI+AI		0.05	0.08	0.10
R+P		FI+AI		0.05	0.08	0.00
Unsegmented				0.10	0.08	0.15

R = Rozelle segment, P = Promontory segment, FI = Fremont Island segment, AI = Antelope Island segment

Tony Crone expressed concern about possible coseismic rupture of the Carrington fault during a Great Salt Lake fault zone earthquake. Jim pointed out that there is no indication from geophysical data that the Carrington fault and Great Salt Lake fault merge.

Background Earthquakes and Consensus Wasatch Front Earthquake Catalog

Walter Arabasz reviewed the current status and steps necessary to develop a consensus earthquake catalog for the WGUEP study area, initiated a discussion on how to handle background earthquakes in relation to fault sources, and reviewed the steps necessary to move forward with a consensus catalog. Walter has initiated discussions with Chuck Mueller, USGS, to begin developing a consensus UUSS/USGS catalog (1850 through 2010). Outstanding issues include the bounds of the area to be covered (larger than WGUEP area?), the magnitude threshold for unifying the UUSS and USGS catalogs, and the need to account for special studies of some main shocks. Walter's recommended path forward includes:

1. Decide/agree on the scope and rigor of the steps applied to analyze the earthquakes in the joined catalogs,

2. Move in the direction of a consensus catalog with the USGS,

3. Revisit whether the probability of a $M \geq 5.0$ background earthquake is to be computed for the entire WGUEP study region or on some gridded basis (as is being done on the USGS website), and

4. Complete the agreed upon steps and analysis.

After considerable discussion, the Working Group decided to form a Seismology Subgroup consisting of Walter, Ivan, Jim, and Mark to determine a methodology for evaluating the earthquake catalogs.

Wasatch Front "Other Faults" Model

Bill Lund reviewed the current iteration of the WGUEP "Other Faults" database. Paleoseismic information for faults in the database comes from the USGS Quaternary Fault and Fold Database of the United States (2011) and from a Quaternary fault characteristics database developed by URS. Review of the URS data identified several faults previously deleted from the WGUEP database that warranted re-evaluation to determine if they should be reinstated to the database. Most of the faults in question add length to other faults or fault zones and thus increase potential earthquake magnitudes. Additionally, the URS database identified several groups of faults that logically could be combined into longer, possibly segmented fault zones.

Bill went through each of the faults in the WGUEP database describing available paleoseismic information (often minimal) and any assumptions made regarding fault parameters such as fault length and dip. Five faults in the database (Crater Bench faults, Drum Mountain fault zone, East Dayton-Oxford fault, Sheeprock fault zone, Rock Creek fault) had not been previously characterized by URS, so Bill asked the Working Group to carefully scrutinize the parameters he had assigned to each of these faults.

Discussion then focused on dips to be assigned to faults where good information about actual fault dip is lacking. URS uses a default dip range of 30-55-70 degrees. The USGS uses 50 ± 10 degrees for the NSHMs as recommended by the BRPEWG (2005). After considerable discussion, the Working Group came to consensus on 50±15 degrees as the default dip range for the WGUEP "Other Faults" database.

Discussion than turned to the East Canyon fault and Joes Valley fault zone, both previously dropped from the WGUEP "Other Faults" database, but for which new U.S. Bureau of Reclamation (USBR) information is available. The consensus of the Working Group was that because the East Canyon fault lacks evidence of Quaternary movement it need not be considered further in the WGUEP probability analysis. There are considerable data to indicate that the Joes Valley fault zone is not seismogenic, and in 2005, the UGS recommended to the USGS that the Joes Valley faults be reclassified as "B" faults in the USGS Fault and Fold Database of the United States. That reclassification did not occur, and the USBR continues to study the Joes Valley fault zone because of its close proximity to the USBR Joes Valley Dam. The Working Group did not reach consensus regarding whether or not to reinstate the Joes Valley fault zone in the WGUEP "Other Faults" database.

Bill was instructed to recalculate the slip rates for the faults in the "Other Faults" database using a dip of 50±15 degrees, to convert slip rates reported in the database from net (down dip) to vertical slip, and to recalculate M_{max} for the faults according to the procedures recommended by Susan and David and adopted by the Working Group (see above).

TASK LIST

Ivan summarized the tasks to be completed for the next WGUEP meeting.

1. Recurrence Model Subgroup (Ivan, Walter, and Jim) to develop a set of strawman recurrence models and weights for the Working Group's consideration.

2. Validate comparison of geodetic, historical earthquake, and geologic moment rates and provide a recommendation on how to incorporate GPS horizontal extension data in the WGUEP probability forecast – Christine.

3 Weight WFZ rupture scenarios, sum moment release per segment per scenario, compute and plot magnitude frequency distributions for rupture scenarios – Paleoseismology Subgroup.

4 Evaluate software for running a Brownian Passage Time probability model/evaluate other probability models – Nico, Patricia.

5 Revise historical earthquake catalog – Seismology Subgroup (Walter, Ivan, Jim, Mark).

6 Decide on final WGUEP scientific products (full model building or simplified product) – Ivan and Mark.

7 Recompute vertical slip rates and M_{max}, and devise a reliability indicator for the paleoseismic data in the WGUEP "Other Faults" database.

8 Determine what to use as the maximum magnitude background earthquake (M 6.75± [no ± specified as per Ivan], M 6.6±0.2, other?) – Ivan, Mark

REFERENCES

Hylland, M.D., and Machette, M.N., 2008, Surficial geologic map of the Levan and Fayette segments of the Wasatch fault zone, Juab and Sanpete Counties, Utah: Utah Geological Survey Map 229, 37 p., 1 plate, scale 1:50,000. http://geology.utah.gov/online/m/m-229.pdf

Lund, W.R., 2005, Consensus preferred recurrence-interval and vertical slip-rate estimates – Review of Utah paleoseismic-trenching data by the Utah Quaternary Fault Parameters Working Group: Utah Geological Survey Bulletin 134, variously paginated, CD. http://ugspub.nr.utah.gov/publications/bulletins/B-134.pdf

Lund, W.R., editor, 2006, Basin and Range Province Earthquake Working Group seismic-hazard recommendations to the U.S. Geological Survey National Seismic Hazard Mapping Program: Utah Geological Survey Open-File Report 477, 23 p. http://ugspub.nr.utah.gov/publications/open_file_reports/OFR-477.pdf

Note: Presenters did not provide complete citations for the remaining references (see citations above) given in their presentations and reported in these minutes.

NEXT MEETING

The next WGUEP meeting is scheduled for June 28 & 29, 2011 in Room 2000 of the Utah Department of Natural Resources Building (1594 West North Temple, Salt Lake City, Utah).

ATTACHMENT 1

Members
Working Group on Utah Earthquake Probabilities

Walter Arabasz, UUSS
Tony Crone, USGS
Chris DuRoss, UGS
Nico Luco, USGS
Bill Lund, UGS, Coordinator
Susan Olig, URS Corporation
James Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
Dave Schwartz, USGS (participated via phone)
Bob Smith, UUGG*
Patricia Thomas, URS Corporation
Ivan Wong, URS Corporation, Chair
Steve Bowman, UGS Liaison to WGUEP
*Absent

Others presenting or assisting the Working Group
Christine Puskas, UUGG
Mike Hylland, UGS

Visitors
Wu-Lung Chang, UUGG
Sarah Derouin, USBR
Kathy Haller, USGS
Lucy Piety, USBR

ATTACHMENT 2
ORIGINAL AGENDA
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #4
Wednesday/Thursday, February 16 & 17, 2011
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

<u>16 February 2011</u>

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome	Bill
8:15 – 8:30	Overview of Agenda	Ivan
8:30 – 9:15	WGUEP Strawman Logic Tree and Products	Ivan
9:15 – 10:00	Recurrence Models	Ivan
10:00 – 10:15	Break	
10:15 – 10:30	Final Wasatch Central Segment Recurrence Rates	Chris
10:30 – 10:45	Final Recurrence Rates for Wasatch Fault End Segments	Mike
10:45 – 11:30	Methods for Estimating Mmax	Susan/David
11:30 – 12:15	Time-Dependent Models	Patricia
12:15 – 1:15	Lunch	
1:15 – 2:15	Comparison of Paleoseismic, Seismicity, and Geodetic Moment Rates	Christine/Bob
2:15 – 3:00	Horizontal Strain Rates From Slip Rate and Geodetic Data	Mark
3:00 – 3:15	Break	
3:15 – 4:00	Moment Balancing the Wasatch Fault	Mark
4:00 – 4:45	Consensus Wasatch Front Earthquake Catalog	Walt/Jim
4:45 – 5:15	Wrap-up Discussion	All
5:15	Adjourn	

<u>17 February 2011</u>

7:30 – 8:00	Continental Breakfast	
8:00 – 8:30	Strawman Rupture Scenarios for the Great Salt Lake Fault	Jim
8:30 – 10:00	Final Wasatch Front Fault Model	Bill
10:00 – 10:15	Break	
10:15 – 11:30	Discussion on Calculating Time-Dependent and Time-Independent Rates	All
11:30 – 12:30	Lunch	
12:30 – 1:30	Discussion on Final Products and Report	All
1:30 – 2:00	Meeting 5 Schedule	
2:00	Adjourn	

<u>WGUEP Members</u>

Ivan Wong, URS (Chair)	Jim Pechmann, UUSS	Chris DuRoss, UGS
Bill Lund, UGS (Coordinator)	Steve Personius, USGS	Susan Olig, URS
Walter Arabasz, UUSS	Mark Petersen, USGS	Bob Smith, UUGG
Tony Crone, USGS	David Schwartz, USGS	Nico Luco, USGS

<u>Other Participants</u>

Patricia Thomas, URS	Steve Bowman, UGS	Mike Hylland, UGS
Christine Puskas, UUGG		