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FINAL TECHNICAL REPORT
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES: COLLABORATIVE RESEARCH BETWEEN THE UTAH GEOLOGICAL SURVEY AND URS CORPORATION

Submitted by
William R. Lund[1] and Ivan G. Wong[2]

[1]Utah Geological Survey
88 E. Fiddler Canyon Road, Suite C
Cedar City, UT 84721
(435) 865-9034; (435) 865-9037 (fax)
billlund@utah.gov

[2]URS Corporation
1333 Broadway, Suite 800
Oakland, CA 94612
(510) 874-3014; (510) 874-3268 (fax)
Ivan.Wong@urs.com

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CONTENTS

FIGURES

TABLES

FINAL TECHNICAL REPORT
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ABSTRACT

The Working Group on Utah Earthquake Probabilities (WGUEP) is making a probabilistic earthquake forecast for the Wasatch Front region of Utah, Idaho, and Wyoming. The WGUEP is calculating both time-independent and, where data permits, time-dependent probabilities for moderate to large (**M** $\geq$ 5.0) earthquakes for intervals ranging from annually to 100 years. While chiefly focused on the Wasatch and Oquirrh-Great Salt Lake fault zones, for which relatively abundant paleoseismic data are available, the forecast also includes 46 lesser studied faults within the Wasatch Front region and background seismicity.

This Final Technical Report summarizes activities of the WGUEP for the two-year period December 1, 2010, to November 30, 2012. Originally conceived as a two-year project, unforeseen technical needs chiefly related to revising and updating the paleoseismic record for the Wasatch fault zone, compiling a new consensus historical earthquake catalog for the WGUEP study region, and adapting methodologies employed by the Working Group on California Earthquake Probabilities and the Central and Eastern United States Seismic Source Characterization study to the Wasatch Front region necessitated extending WGUEP activities for a third year (12/01/2012 – 11/30/2013). Consequently, final WGUEP results are not yet complete and are not reported here. This report summarizes work performed by the WGUEP to date and provides information on technical issues that have surfaced during the working group process. Summaries of the nine WGUEP meetings held to date and associated PowerPoint presentations are available at http://geology.utah.gov/ghp/workgroups/wguep.htm. The WGUEP final report is scheduled for release in late 2013.

INVESTIGATION UNDERTAKEN

The purpose of this project, undertaken by the Working Group on Utah Earthquake Probabilities (WGUEP), is to make a probabilistic earthquake forecast for the Wasatch Front region (figure 1) of Utah, Idaho, and Wyoming. A consensus-based estimate of earthquake probabilities for the Wasatch Front will help heighten policy makers' and the public's awareness and understanding of the region's seismic hazards. Time-dependent and time-independent earthquake forecasts can be directly incorporated into site-specific probabilistic seismic hazard analyses (PSHAs) for the design and seismic safety evaluation of critical structures and facilities. Additionally, Wasatch Front urban hazard maps are planned by the U.S. Geological Survey (USGS), and time-dependent probabilities can also be incorporated into the PSHAs that will form the basis of those maps. Earthquake probabilities will also eventually be incorporated into the USGS National

Figure 1. Wasatch Front region as defined for the WGUEP earthquake forecast.

Seismic Hazard Maps and the National Earthquake Hazards Reduction Program building code provisions. Finally, earthquake probabilities developed and reviewed by the earth science community can help inform public policy and drive greater and more sustained earthquake mitigation efforts in the Wasatch Front region.

The goal of this project is to calculate the probability of moderate to large earthquakes (**M** $\geq$ 5.0) in the Wasatch Front region for a range of intervals varying from annually to 100 years. Time-dependent and time-independent probabilities that will be estimated include:

- Segment-specific, time-dependent and time-independent probabilities of the characteristic earthquake on the five central segments of the Wasatch fault zone (WFZ).
- Time-dependent and time-independent probabilities for the whole WFZ for **M** 6.5 and greater and **M** 7.0 and greater events.
- Segment-specific and fault-specific, time-dependent and time-independent probabilities for the Oquirrh-Great Salt Lake fault zone.
- Time-independent probabilities for 46 other "significant" faults in the Wasatch Front region.
- Time-dependent and time-independent probabilities for the Wasatch Front region for a range of magnitudes starting at **M** $\geq$ 5.0.
- Time-independent probability for background earthquakes in the Wasatch Front region for a range of magnitudes starting at **M** $\geq$ 5.0.
- Map of time-dependent probabilities for the Wasatch Front region.

Epistemic uncertainties in all input parameters are being explicitly addressed using logic trees.

WORK PERFORMED TO DATE

The WGUEP has met nine times since February 2010, at the Utah Department of Natural Resources Building in Salt Lake City, Utah. Six of those meetings occurred during the time period covered by this final technical report. The meetings were hosted by the Utah Geological Survey (UGS). WGUEP accomplishments to date include:

1. Developed an earthquake chronology for the five central WFZ segments with multiple Holocene surface-faulting earthquakes. Selected single and multiple-segment rupture scenarios for those segments.
    - Examined the original paleoseismic site investigation reports and associated trench logs/maps to evaluate geologic and chronologic evidence for interpreted events.
    - Considered common limitations in dating paleoearthquake event horizons.
    - Constructed time-stratigraphic OxCal models for each site.

- Qualitatively correlated events between sites to develop segment-wide earthquake histories.
- Computed a composite probability distribution function (PDF) for each earthquake.
- Used the composite earthquake PDFs to construct segment-wide PDF data to calculate mean recurrence and evaluate associated uncertainties.
- Analyzed available displacement data, and in conjunction with the recurrence data calculated mean slip rates (open and closed interval) for each segment.

2. Characterized the northern and southern end segments of WFZ.
   - Evaluated available paleoseismic data and determined mean segment slip rate and recurrence intervals where data permitted.
   - Developed rupture scenarios for each segment
3. Characterized the Oquirrh-Great Salt Lake fault zone system.
   - Evaluated available paleoseismic data and determined recurrence intervals for the Fremont and Antelope Island segments of the Great Salt Lake fault zone and slip rates for the remaining segments.
   - Developed rupture scenarios for each segment and for multiple segment ruptures.
4. Characterized (rupture model, probability of activity, length, slip rate, recurrence where available) the 46 other faults in the Wasatch Front Region considered significant to the WGUEP earthquake forecast.
5. Developed rupture models (coseismic/independent) for the subsidiary faults of four antithetic fault pairs in the WGUEP study region.
   - West Valley fault zone: Coseismic with the Salt Lake City segment of the WFZ (0.75)/Independent (0.25)
   - Utah Lake faults: Coseismic with the Provo segment of the WFZ (0.5)/Independent (0.25)
   - Hansel Valley fault: Coseismic with the North Promontory fault (0.4)/Independent (0.6)
   - Western Bear Lake fault: Coseismic with the Eastern Bear Lake fault (0.5)/Independent (0.5)
6. Currently in the process of compiling a new consensus historical earthquake catalog through 2010, for the WGUEP study region.
7. Developed a methodology to estimate M_{MAX} for faults in the study region. The magnitude regressions selected and their weights are as follows:

Table 1. Magnitude regressions for estimating M_{MAX} for the WGUEP earthquake forecast.

M_W Relation	Parameter	Mw formula	A faults[1]	B faults[2]	C faults[3]
Hanks and Kanamori (1979)	M_0	$2/3\log(M_0)-10.7$	0.45	0.4	0.25
Stirling and others (2002)	SRL - censored	$5.88+0.80\log(SRL)$	0.45	0.4	0.25
Wesnousky (2008)	SRL – all fault types	$5.30+1.02\log(SRL)$	0.05	0.1	0.25
Wells and Coppersmith (1994)	SRL – all	$5.88+1.16\log(SRL)$	0.05	0.1	0.25

[1] - A faults (segmented with 2+ paleoseismic trench sites)
[2] - B faults (one paleoseismic trench site)
[3] - Category C faults (no paleoseismic trench data)

8. Adopted a background earthquake M_{MAX} of **M** 6.75 ± 0.25. USGS recurrence approach (e.g., recurrence models) is being used.
9. Adopted a range of crustal fault dips of 50 ± 15 degrees as recommended to the USGS by the Basin and Range Province Earthquake Working Group II (Lund, 2012) for normal faults in the Basin and Range Province. Exceptions are the Joes Valley fault zone and the Snow Lake graben, which based on seismic-profile information and structural relations, are assigned a dip of 70 ± 15 degrees. Dips are weighted as follows: 35/55 (0.3), 50/70 (0.4), 65/85 (0.3).
10. Analyzed earthquake hypocenter data for the Wasatch Front region and adopted a range of seismogenic crustal depths of 15 ± 3 km weighted as follows:
    - East of WFZ 12 km (0.1), 15 km (0.7), 18 km (0.2)
    - West of WFZ 12 km (0.2), 15 km (0.7), 18 km (0.1)
11. Compared moment rates derived from available geodetic, historical seismicity, and paleoseismic data. A discrepancy remains between geodetic rates and the paleoseismic and historical seismicity-based rates that is difficult to reconcile; the geodetic rates are at least 50% higher. The WGUEP will use the geodetic data as a constraint on regional moment rates.
12. Developing recurrence interval PDFs from the earthquake data set (22 events) available for the five central WFZ segments using both the Poisson rate parameter λ (lambda) and the Brownian Passage Time (BPT) repeat time parameter μ (mu). The WGUEP has adopted the approach used in the Central and Eastern United States (CEUS) Seismic Source Characterization (SSC) report (U.S. Nuclear Regulatory Commission, 2012) for calculating those parameters.
13. Completed two preliminary rounds of probability calculations for the faults in the Wasatch Front Region. Based on those results, input values and computation techniques are being refined.
14. Draft final report writing is in progress.

PROBLEMS ENCOUNTERED

Although the WGUEP is employing a methodology similar to that used in the Uniform California Earthquake Rupture Forecast (Working Group on California Earthquake Probabilities, 2008), numerous technical issues unique to normal-slip faults, and particularly to the normal-slip fault database available for the Wasatch Front region, have presented difficulties/uncertainties that have taken more time than anticipated to resolve. Among those issues are:

- Developing the earthquake chronology for the five central WFZ segments required a complete re-evaluation of all legacy and contemporary paleoseismic data (more than 50 trenches at multiple sites along the fault). The timing for each earthquake (22 total events) was recalculated and placed in an OxCal model to develop PDFs for each earthquake and for the segments as a whole. Much of this effort involved new science and has resulted in

two significant publications (DuRoss and others, 2011, and Personius and others, 2012) with more to follow.

- Developing a model for potentially coseismic antithetic fault pairs in the WGUEP was not a task anticipated when the project began, and has required considerable review and application/refinement of new evaluation techniques.

- Compiling a new consensus historical earthquake catalog for the WGUEP study area has proven far more complex than anticipated. The chief issues include deriving relations between M_w and other earthquake magnitude scales, assessing magnitude uncertainties and rounding errors, assessing catalog completeness including removing duplicates and non-tectonic events, and assessing magnitude scaling issues. Additionally, assistance is required from the USGS with integrating their catalog, and the USGS staff has had competing priorities for their attention and have as yet been unable to devote the necessary time to this task.

- Developing the best methodology for estimating M_{MAX} required a detailed evaluation/comparison of more than 25 magnitude regression relations to determine those best suited for use with Basin and Range normal-slip faults. For several of the regressions, the evaluation included correspondence with the regression authors to fully evaluate the fault databases used and to determine regression limitations.

- Considerable effort has been expended comparing moment rates derived from geodetic, historical earthquake, and paleoseismic data sets to evaluate rate discrepancies and to resolve how to incorporate the geodetic data in the WGUEP forecast.

- Adapting the methodologies for developing recurrence PDFs from the CEUS SSC report (U.S. Nuclear Regulatory Commission, 2012) for the WGUEP data set has required considerable effort, particularly with regard to grouped earthquake data and multisegment ruptures, and all issues are not yet resolved.

PUBLICATIONS AND PRESENTATIONS

DuRoss, C.B., Personius, S.F., Crone, A.J., Olig, S.S., and Lund, W.R., 2011, Integration of paleoseismic data from multiple sites to develop an objective earthquake chronology– Application to the Weber segment of the Wasatch fault zone: Bulletin of the Seismological Society of America, v. 101, no. p. 2765–2781.

Personius, S.F., DuRoss, C.B., and Crone, A.J., 2012, Holocene behavior of the Brigham City segment – implications for forecasting the next large-magnitude earthquake on the Wasatch fault zone, Utah, USA: Bulletin of the Seismological Society of America, v. 102, no. 6, p. 2265-2281.

Wong, I., Lund, W., DuRoss, C., Arabasz, W., Pechmann, J., Crone, A., Luco, N., Personius, S., Petersen, M., Olig, S., and Schwartz, D., 2011, The Working Group on Utah Earthquake

Probabilities (WGUEP) – background and goals [abs.]: Seismological Research Letters, v. 82, no. 2, p. 345–346.

Wong, I., Lund, W., DuRoss, C., Thomas, P., Arabasz, W., Crone, A., Hylland, M., Luco, N., Olig, S., Pechmann, J.C., Personius, S., Petersen, M., Schwartz, D., and Smith, R., 2012, Forecasting large earthquakes along the Wasatch Front, Utah [abs]: AEG News, 2012 Annual Meeting Program with Abstracts, v. 55, p. 85.

Additionally, summaries of the nine WGUEP meetings and associated PowerPoint presentations are available on the UGS website at http://geology.utah.gov/ghp/workgroups/wguep.htm.

REFERENCES

DuRoss, C.B., Personius, S.F., Crone, A.J., Olig, S.S., and Lund, W.R., 2011, Integration of paleoseismic data from multiple sites to develop an objective earthquake chronology–Application to the Weber segment of the Wasatch fault zone: Bulletin of the Seismological Society of America, v. 101, no. p. 2765–2781.

Hanks, T.C., and Kanamori, H., 1979, A moment magnitude scale: Journal of Geophysical Research, v. 84, p. 2348-2350.

Lund, W.R., 2012, Basin and Range Province Earthquake Working Group II—Recommendations to the U.S. Geological Survey National Seismic Hazard Mapping Program for the 2014 update of the National Seismic Hazard Maps: Utah Geological Survey Open-File Report 591, 17 p., available at http://geology.utah.gov/online/ofr/ofr-591.pdf.

Personius, S.F., DuRoss, C.B., and Crone, A.J., 2012, Holocene behavior of the Brigham City segment – implications for forecasting the next large-magnitude earthquake on the Wasatch fault zone, Utah, USA: Bulletin of the Seismological Society of America, v. 102, no. 6, p. 2265-2281.

Stirling, M., Rhoades, D., and Berryman, K., 2002, Comparison of earthquake scaling relations derived from data of the instrumental and preinstrumental era: Bulletin of the Seismological Society of America, v. 92, no. 2, p. 812-830.

U.S. Nuclear Regulatory Commission, 2012, Technical report—Central and Eastern United States seismic source characterization for nuclear facilities: Washington, D.C. and Palo Alto, California, Electric Power Research Institute, U.S. Department of Energy, and U.S. Nuclear Regulatory Commission joint research report, variously paginated, available at http://pbadupws.nrc.gov/docs/ML1204/ML12048A804.pdf.

Wells, D.L., and Coppersmith, K.J., 1994, New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement: Bulletin of the Seismological Society of America, v. 84, p. 974-1002.

Wesnousky, S.G., 2008, Displacement and geometrical characteristics of earthquake surface ruptures—Issues and implications for seismic-hazard analysis and the process of earthquake rupture: Bulletin of the Seismological Society of America, v. 98, p. 1609–1632.

Wong, I.G., Thomas, P.A., and Olig, S.S., 2007, Why time-dependent hazard should be incorporated into the National Hazard Maps [abs.]: Seismological Research Letters, v. 78, p. 263.

Working Group on California Earthquake Probabilities (WGCEP), 2008, The Uniform California Earthquake Rupture Forecast, version 2 (UCERF2): U.S. Geological Survey Open-File Report 2007-1437, variously paginated, available online at http://pubs.usgs.gov/of/2007/1437/.