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UTAH EARTHQUAKE WORKING GROUPS AND WASATCH FRONT URBAN SEISMIC HAZARD MAPS

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ABSTRACT

The Utah Geological Survey (UGS) and the U.S. Geological Survey (USGS) continued collaborative earthquake-hazard studies in Utah under a three-year cooperative agreement (calendar years [CY] 2010 to 2012) that builds on the highly successful framework (Utah Earthquake Working Groups) developed under previous cooperative agreements (03HQAG008 and 07HQAG0003) which extended from CY 2003 to CY 2009. The current earthquake research working groups consist of the Utah Quaternary Fault Parameters Working Group, Ground Shaking Working Group, Utah Liquefaction Advisory Group, and a new group, the Working Group on Utah Earthquake Probabilities. The CY 2010 to 2012 cooperative agreement ensured that the annual Utah Earthquake Working Groups meetings were held to support the USGS in developing Wasatch Front urban seismic hazard maps and updating the National Seismic Hazard Maps, updating various earthquake-related databases, hosting the Wasatch Front Community Velocity Model, reviewing investigation results, updating long-term plans, and helping coordinate National Earthquake Hazards Reduction Program (NEHRP) related research in Utah.

During 2010-12, the UGS also (1) performed several scientific investigations to map and characterize faults, (2) provided assistance to USGS and NEHRP researchers, (3) published reports of completed research, (4) continued earthquake-related public outreach, and (5) enhanced our website with updates and/or new pages for the Paleoseismology of Utah publication series and geologic hazard data.

INTRODUCTION

The Utah Geological Survey (UGS) and the U.S. Geological Survey (USGS) continued collaborative earthquake-hazard studies in Utah under a cooperative three-year agreement (calendar years [CY] 2010 to 2012) that builds on the efforts of previous cooperative agreements (03HQAG008 and 07HQAG0003) which extended from CY 2003 to CY 2009. The CY 2010 to 2012 cooperative agreement ensured that the annual Utah Earthquake Working Groups meetings were held to support the USGS in developing Wasatch Front urban seismic hazard maps and updating National Seismic Hazard Maps, updating various earthquake-related databases, hosting the Wasatch Front Community Velocity Model (WFCVM), reviewing investigation results, updating long-term plans, and helping coordinate National Earthquake Hazards Reduction Program (NEHRP) related research in Utah. The groups currently consist of the Utah Quaternary Fault Parameters Working Group, Ground Shaking Working Group, Utah Liquefaction Advisory Group, and a new group, the Working Group on Utah Earthquake Probabilities.

RESULTS

Utah Earthquake Working Groups

The UGS, in cooperation with the USGS and the Utah Seismic Safety Commission, convened Utah Earthquake Working Groups meetings each February over the period of this cooperative agreement at the Department of Natural Resources Building in Salt Lake City, Utah. The Utah Quaternary Fault Parameters Working Group, Ground Shaking Working Group, and Utah Liquefaction Advisory Group met to review research activities, re-evaluate long-term plans for producing maps, and develop partnerships for investigations and topics for future NEHRP proposals. The Working Group on Utah Earthquake Probabilities met during the three February meetings, and also in July 2010, December 2010, June 2011, November 2011, and August 2012. Working group members are listed in appendix 1. Results of the working group meetings were reported in Annual Progress Reports for CY 2010 and 2011 (Bowman, 2010, 2011), in this Final Technical Report (including appendices 2 and 3), and on the UGS website (working group meeting agendas, summaries, and presentations) as described in the Data Availability section below.

The working groups have achieved consensus regarding the types of earthquake hazard maps needed, new data required, and preferred data collection and mapping techniques. The working groups developed partnerships and identified projects to pursue for funding. These results have been used by the USGS to develop Utah priorities for the annual USGS NEHRP external research support grant opportunity announcement for Intermountain West (IMW panel) projects [see http://geology.utah.gov/ghp/workgroups/index.htm, Utah Priorities for the Annual USGS Earthquake Hazards Program External Research Support Announcement (NEHRP RFP) section]. Because the meetings were held in February each year, prior to the annual USGS NEHRP grant opportunity release, discussions and momentum gained at the meetings were transferred to the opportunity release and subsequently translated into proposals by researchers to the USGS.

Working group members (appendix 1) include geologists, engineers, seismologists, and geophysicists from the USGS, UGS, University of Utah, Utah State University, Brigham Young University, and various consulting companies and state agencies. In addition, representatives from the Utah Seismic Safety Commission, Utah Division of Emergency Management, American Society of Civil Engineers, Association of Environmental and Engineering Geologists, Salt Lake County, Utah Division of Water Rights – Dam Safety Program, and other organizations were invited to attend the meetings.

WSSPC 2012 National Awards in Excellence for Research

The Western States Seismic Policy Council (WSSPC) awarded the 2012 National Awards in Excellence for Research to the Utah Earthquake Working Groups at the 2012 National Earthquake Conference in Memphis, Tennessee (http://www.wsspc.org/awards/current.shtml and http://www.wsspc.org/awards/2012/2012UtahWorkingGroupsFINAL.pdf) for the working groups' innovative and highly successful framework for collaborating and fostering earthquake research in Utah. The award recognized 59 scientists, the UGS, the USGS, and the Utah Seismic Safety Commission for their contributions to the working groups. The award nomination form is contained in appendix 4.

Utah Quaternary Fault Parameters Working Group

The main goal of the Utah Quaternary Fault Parameters Working Group (UQFPWG) is to characterize active earthquake fault sources in Utah. The working group began by developing consensus slip-rate and recurrence-interval data for all Utah trenched faults (Lund, 2005). The working group also developed a priority list of faults requiring additional study and, based on each year's paleoseismic investigations, has updated the list annually. As new paleoseismic data became available, the working group has modified its consensus slip-rate and recurrence-interval values as necessary. Other working group issues included the generalization of the surface trace of the Salt Lake City segment of the Wasatch fault zone (WFZ) on the National Seismic Hazard Maps (NSHM), and the relation of the West Valley fault zone to the Salt Lake City segment of the WFZ. In addition, the working group and the UGS made recommendations regarding which faults should be included in future USGS NSHM updates.

In 2010, the UQFPWG discussed the results of several paleoseismic investigations in Utah, and an updated chronology of surface-faulting earthquakes on the Weber segment of the WFZ. Presentations and subsequent discussions included:

- Brigham City segment, trenching update; Tony Crone/Steve Personius, USGS
- Washington fault northern segment, trenching update; Bill Lund/Tyler Knudsen, UGS
- Washington fault Southern Beltway trenching investigation; Dave Simon, Simon - Bymaster, Inc.

- U.S. Bureau of Reclamation Utah fault studies update; Larry Anderson, USBR
- Bear River fault zone, trenching update; Suzanne Hecker, USGS
- Salt Lake City segment/West Valley fault zone investigation, progress report: Mike Hylland, UGS
- Working Group on Utah Earthquake Probabilities; Ivan Wong, URS Corp.
- A scheduled presentation by Jim Evans, USU, on the East Cache fault zone trenching study was cancelled because Jim failed to attend the meeting.

UQFPWG 2010 priorities for paleoseismic fault investigations (listed in priority order) included:

1. Warm Springs fault / East Bench fault subsurface geometry and connection.
2. Provo-segment penultimate event.
3. Long-term earthquake record of the Nephi segment of the WFZ.
4. Washington fault.
5. Mid- to late-Holocene earthquake chronology, southern part of the Weber segment of the WFZ.

In 2011, the UQFPWG discussed the results of several paleoseismic investigations in Utah, and recommendations to the USGS for the *Quaternary Fault and Fold Database of the United States* regarding the Joes Valley fault zone and the East Canyon and Main Canyon (East of East Canyon) faults. Presentations and subsequent discussions included:

- Preliminary results from the Penrose Drive trench on the Salt Lake City segment; Chris DuRoss, UGS
- Update on fault trenching at the Baileys Lake site, West Valley fault zone; Mike Hylland, UGS
- A brief summary of recent work on the northern Nephi segment of the Wasatch fault, Utah; Daniel Horns, Utah Valley University
- Joes Valley fault zone; Lucy Piety, U.S. Bureau of Reclamation (USBR)
- Main Canyon and East Canyon faults; Lucy Piety, USBR
- Interactive Utah Quaternary fault map demonstration; Corey Unger and Mike Hylland, UGS
- HAZDOCS document archive presentation and progress report on UGS publishing USBR seismotectonic reports in the Paleoseismology of Utah series; Steve Bowman, UGS
- Utah Lake faults study – Preliminary progress report as of 2/15/2011; David Dinter, University of Utah Department of Geology and Geophysics
- Update on the Working Group on Utah Earthquake Probabilities; Ivan Wong, URS Corp.
- Integration of paleoseismic data from multiple sites to develop an objective earthquake chronology – Application to the Weber segment of the Wasatch fault zone, Utah; Chris DuRoss, UGS
- Implementation: The third dimension of seismic hazard mitigation; Ron Harris, Brigham Young University
- A scheduled presentation by Jim Evans, Utah State University, on the East Cache fault zone trenching study was cancelled because Jim failed to attend the meeting.

UQFPWG 2011 priorities for paleoseismic fault investigations (not in priority order) included:

- Brigham City segment, WFZ rupture extent (north and south ends)
- Long-term earthquake record Nephi segment, WFZ
- Long-term earthquake record northern Provo segment, WFZ
- Long-term earthquake record southern Weber segment, WFZ
- Penultimate event Provo segment, WFZ

- West Valley fault zone – Taylorsville fault

In 2012, the UQFPWG discussed the results of several paleoseismic investigations in Utah; an issue regarding the status of a NEHRP-funded investigation titled *Earthquake Timing on the Southern Segment of the East Cache Fault Zone, Utah* by Utah State University (USU); possible evidence for previously unrecognized Quaternary faulting in northern Utah by USU; and reviewed, discussed, and revised the UQFPWG priorities for paleoseismic investigations in Utah. Presentations and subsequent discussions included:

- Paleoseismicity of the Salt Lake City segment—Results from the Penrose Drive trench investigation; Chris DuRoss, UGS
- Update on fault trenching at the Baileys Lake site, West Valley fault zone; Mike Hylland, UGS
- Searching for evidence of seismic events in lacustrine sediments in Utah Lake; Quincy Nickens, Brigham Young University
- Hurricane Cliffs hydropower and Lake Powell pipeline preliminary Quaternary fault investigation; Dean Ostenaa, Fugro, Inc.
- Blue Castle licensing project; Dean Ostenaa, Fugro, Inc.
- Summary of preliminary investigations of the Paunsaugunt fault, Utah; Bob Kirkham, RJH Consultants (no Power Point, hard copy handout)
- Utah Geological Survey Nephi-segment trenching project, June 2012: Chris DuRoss, UGS
- Characterizing the central Wasatch fault zone for the Working Group on Utah Earthquake Probabilities; Chris DuRoss, UGS
- Comparison of moment rates from GPS observations and late Quaternary earthquakes on the Wasatch fault, Utah; Christine Puskas, UNAVCO
- The Working Group on Utah Earthquake Probabilities (WGUEP)—Background, goals, and progress; Ivan Wong, URS Corporation
- Basin and Range Province Earthquake Working Group II; Bill Lund, UGS

UQFPWG 2012 priorities for paleoseismic fault investigations (not in priority order) included:

- Acquire new paleoseismic information in data gaps along the five central segments of the WFZ.
    - Brigham City segment rupture extent (north and south ends)
    - Long-term earthquake record northern Provo segment
    - Long-term earthquake record southern Weber segment
- Penultimate event Provo segment, WFZ
- West Valley fault zone – Taylorsville fault

Ground Shaking Working Group

The Ground Shaking Working Group (GSWG) continued toward its goal of developing urban seismic hazard maps along the Wasatch Front. The GSWG discussed ongoing studies related to seismic source models for future urban seismic hazard maps, gave updates on the Wasatch Front Community Velocity Model (WFCVM), and on the future development of urban seismic hazard maps. The current version of the WFCVM, version 3c, is available on the UGS website (http://geology.utah.gov/ghp/consultants/geophysical_data/cvm.htm).

In 2010, the GSWG discussed ongoing studies related to analysis of Advanced National Seismic System (ANSS) data for stress drop and kappa, sonic log analyses for the WFCVM, USGS plans for analysis of the WFCVM, several studies using the WFCVM, and gave an update on modifications to the WFCVM. Future priorities included:

- Coordination and interaction between WFCVM modeling groups.
- Test model for validation and verification with short- and long-period ground motion.
- Submit group proposal with long-period ground motion modelers for funding.
- Progress toward dynamic modeling on complex (segmented) faults.
- Continue work toward Wasatch Front urban hazard maps.

In 2011, the GSWG discussed ongoing studies related to seismic source models for future urban seismic hazard maps, and gave updates on the WFCVM and the development of urban seismic hazard maps. Future priorities included:

- Combine long- and short-period data – non-linear broadband synthetics.
- Assess the current state of urban hazard map components.
- Define uncertainties in the analysis.
- Determine how map products are presented to users.
- Continue work toward Wasatch Front urban hazard maps, starting in Salt Lake Valley.

In 2012, the GSWG discussed the state of research regarding developing urban seismic hazard maps, how much uncertainty is in the WFCVM, basin effects, the efforts of the different modeling groups, what additional information is needed to produce the Wasatch Front Urban Seismic Hazard Maps, and how the maps are to be presented to users (e.g., hard-copy maps, web-based, interactive, location coordinate input/output). Future priorities include:

- Research into the effect of the East Bench-Warm Springs fault step-over on ground motions.
- Research into the apparent drop off in simulation ground motions relative to the NGA models west of the Wasatch fault.
- WFCVM testing to determine if it needs more work and/or refinement.
- Basin effects, and amplification and de-amplification effects of the shallow unconsolidated sediments need to be incorporated into the urban seismic hazard maps.
- Developing draft Wasatch Front urban seismic hazard maps.

Utah Liquefaction Advisory Group

The Utah Liquefaction Advisory Group (ULAG) continued toward its long-term goal of producing maps showing annual probabilities of liquefaction and liquefaction-induced ground displacement. It focused on extending pilot-project investigations conducted in Salt Lake Valley to Weber and Davis Counties, particularly regarding compilation of a comprehensive regional geotechnical database. The working group discussed issues related to securing funding for additional mapping in urban areas, under-sampling of geologic units, uncertainty analysis, compilation of newly available geotechnical data, and conducting additional cone penetrometer investigations in downtown Salt Lake City. Work is underway to publish liquefaction maps in a format useful for local government planners and other users.

In 2010, the ULAG discussed the status of several projects, including ground-settlement mapping for the Salt Lake Valley, mapping and uncertainty analysis of liquefaction-induced lateral spread displacements for geotechnically under-sampled units, reviews of past work, completed draft maps, and work in progress. ULAG 2010 future priorities included:

- Investigation of structural relations between the Warm Springs and East Bench faults (sub-sections of the Salt Lake City segment of the WFZ).
- Establish a publically accessible geotechnical database.

- Expand liquefaction hazard mapping to Weber County.

In 2011, the ULAG discussed liquefaction resulting from the **M** 4.5 Randolph, Utah earthquake, liquefaction hazard mapping in Weber County, reviews of past work, completed draft maps, and work in progress. ULAG 2011 future priorities included:

- Secure funding for additional mapping in urban areas.
- Establish a publically accessible geotechnical database.
- Expand liquefaction hazard mapping to Weber County.
- Education and outreach to decision makers and local consultants.

The ULAG did not meet in 2012, due to a lack of successful proposals submitted to the USGS NEHRP process for funding. However, work continues toward publication of the Salt Lake County liquefaction hazard maps, development of a model liquefaction ordinance, development of a workshop for local governments addressing implementation of the liquefaction hazard maps, and identifying keynote speakers for education and technology transfer at the 2013 ULAG meeting.

Working Group on Utah Earthquake Probabilities

Over the past two decades, estimates of the probabilities of large earthquakes occurring in a specified time period have been developed for the San Francisco Bay area (Working Group on California Earthquake Probabilities [WGCEP, 1988, 1990, 1999, 2003]), southern California (WGCEP, 1995), and most recently, statewide as part of the Unified California Earthquake Rupture Forecast (UCERF) (WGCEP, 2008). The purpose of these working groups was to calculate time-dependent probabilities of large earthquakes on major faults where the "requisite" information is available on the expected mean frequency of earthquakes and the elapsed time since the most recent large earthquake. Where such information is lacking, time-independent probabilities were estimated for less well-studied faults. The key to reliable earthquake probability forecasts has been the availability of the requisite data.

Previous estimates of earthquake probabilities have been made for Utah's Wasatch Front region by individual researchers (Nishenko and Schwartz, 1990; McCalpin and Nishenko, 1996; Wong and others, 2002) using information available at the time. The results of these investigations had little formal impact on public policy in Utah. The level of information on past earthquakes along the Wasatch Front, along with regional seismicity and geodetic data, are now sufficiently robust to provide the basis for a complete probabilistic estimate of the likelihood of future large earthquakes within the Wasatch Front region.

As data are currently available to support the estimation of probabilities of large earthquakes along the Wasatch Front, the USGS Earthquake Hazards Program, UGS, and URS Corporation (Ivan Wong) jointly concluded in 2009, that establishing a Working Group on Utah Earthquake Probabilities (WGUEP) is both possible and necessary. In 2010, the WGUEP was integrated within the existing Utah Earthquake Working Groups framework. The WGCEPs have developed and refined the methodologies to estimate probabilities, and the WGUEP is now applying that experience to the Wasatch Front.

A significant amount of new paleoseismic data for the WFZ has become available since McCalpin and Nishenko (1996) performed their analysis (Nelson and others, 2006; Olig and others, 2006; Hylland, 2007; DuRoss, 2008; DuRoss and others, 2008; Hylland and Machette, 2008; Machette and others, 2008; DuRoss and others, 2009). The WGUEP earthquake forecast for the Wasatch Front includes both time-dependent probabilities for the five central segments of the WFZ and two segments of the Great Salt Lake fault zone, and time-independent probabilities for other faults in the Wasatch Front region as well as the probability of damaging background earthquakes. The WGUEP is addressing epistemic uncertainties in all input parameters.

Meeting and travel costs for the WGUEP are included in this cooperative agreement; analysis and other costs are part of a separate USGS NEHRP Collaborative Agreement between the UGS and URS Corporation (award no. G11AP20004 and G11AP20010). The WGUEP convened two meetings prior to initiation of NEHRP grants G11AP20004 and G11AP20010 to start the new working group, and subsequently met during the annual Utah Earthquake Working Groups meetings in February to reduce travel costs, and subsequently met in July 2010, December 2010, June 2011, November 2011, and August 2012. Lund and Wong (2011) described the analysis and research conducted by the WGUEP to late 2011, and the WGUEP web page (http://geology.utah.gov/ghp/workgroups/wguep.htm) includes a short description of the WGUEP process, meeting agendas, meeting summaries, and presentations to date.

Basin and Range Province Earthquake Working Group II

Based largely on deliberations of the UQFPWG (since 2006) and the WGUEP, eight questions surfaced in 2011, related either to geologic evaluation of seismic sources or seismology in the Basin and Range Province that are important to the 2014 update of the NSHMs. In response to these questions, the USGS requested that the UGS convene a Basin and Range Province Earthquake Working Group II (BRPEWGII), which the UGS did on November 14 to 16, 2011, at the Department of Natural Resources Building in Salt Lake City, Utah. The BRPEWGII meeting was funded by the USGS through award number G11AP20187 (separate from the Utah Earthquake Working Groups USGS/UGS Cooperative Agreement), the UGS, and WSSPC. Information specific to the BRPEWG process may be found at http://geology.utah.gov/ghp/workgroups/brpewg.htm, and the results of the BRPEWGII meeting were published as UGS Open-File Report 591 (Lund, 2012).

Database Updates

The Ground Shaking Working Group is discussing the need for and analysis of large-scale ground-shaking maps for the Wasatch Front, based on a WFCVM incorporating shallow shear-wave velocity (Vs30) and deep-basin structure, and new liquefaction-hazard maps. The UGS has compiled databases that identify existing data on shallow shear-wave velocities (Vs30), deep-basin structure, geotechnical landslide shear strengths, and Quaternary faults and folds.

We continue to track new geologic mapping and studies of Quaternary faults in Utah for updates to the *Utah Quaternary Fault and Fold Database and Map*. Presently, about two dozen faults and fault sections need updated database files; we have completed draft updates for seven of these. Once through the UGS review process, the revised database files will be forwarded to the USGS for incorporation into the *Quaternary Fault and Fold Database of the United States*.

We continue to develop an interactive map and database of Utah's Quaternary faults and folds that will be accessible through the UGS website. This version of the map and database supplements the USGS *Quaternary Fault and Fold Database of the United States* by highlighting structures for which new data exist, but may not yet be available through the national database. The map will be served on the UGS website with ESRI's ArcServer technology, for user on-the-fly location querying and map generation.

Wasatch Front Community Velocity Model

We are distributing the WFCVM to interested researchers on the UGS website, and have a web page describing the WFCVM and providing information on how to download the data files for use by end-users. The current version of the WFCVM, version 3c, is available at http://geology.utah.gov/ghp/consultants/geophysical_data/cvm.htm. UGS staff have not yet worked with the WFCVM sufficiently to determine our capability to update and make it available as an interactive web-based product.

Assistance to USGS and NEHRP Researchers

Over the three-year period of this cooperative agreement, the UGS provided the following assistance with earthquake-related issues to the USGS, NEHRP researchers, and others in Utah.

- Participated in the USGS-sponsored Workshop on Update of Intermountain West Part of the U.S. National Seismic Hazard Maps held in June 2012 in Salt Lake City, Utah (http://earthquake.usgs.gov/hazards/about/workshops/IMW_workshop/index.php).

- As a member of the Western States Seismic Policy Council (WSSPC), the UGS provided comments on and updates to the following WSSPC Policy Recommendations (PR, http://www.wsspc.org/policy/recommendations.shtml):

    - PR 10-3 Post-Earthquake Technical Clearinghouse
    - PR 10-5 Basin and Range Province Earthquake Working Group(s)
    - PR 10-6 Post-Earthquake Information Management System
    - PR 11-2 Definition of Fault Activity for the Basin and Range Province
    - PR 11-3 Earthquake Monitoring Networks
    - PR 12- 1 Earthquake Planning Scenario
    - PR 12-2 Developing Earthquake Risk-Reduction Strategies

- The UGS participated on the organizing committee for the Association of Environmental and Engineering Geologists 2012 Annual Meeting in Salt Lake City (http://aegweb.org/events/aeg-annual-meeting/2012-salt-lake-city), and organized/led the following earthquake-related meeting activities:

    - Short Course – Seismic Hazard Analysis: Keeping Up With the Science
    - Symposium – Addressing Earthquake Hazards in the Basin and Range Province
    - Field Trip – Geologic Hazards of the Wasatch Front (DuRoss and others, 2012)

- UGS staff assisted Iron County in preparing a geologic hazards ordinance that includes both surface-fault rupture and earthquake ground shaking components.

- UGS staff served as Resource Experts for the Blue Castle Nuclear Power Plant SSHAC Level 3 technical review.

- UGS staff presented the results of both completed and ongoing paleoseismic investigations and the progress of the WGUEP at professional meetings of the Association of Environmental & Engineering Geologists, Geological Society of America, and Seismological Society of America.

- UGS staff made presentations to the Structural Engineers Council of Utah and to the Southwestern Utah Board of Realtors on geologic hazards that included discussions of surface-fault rupture and earthquake ground shaking.

- The UGS developed a draft web-based, open-source Utah Geologic Hazards Clearinghouse to collect and manage data related to significant geologic-hazard events (earthquakes, landslides, etc.). The clearinghouse functions to provide timely geologic-hazard observations for state and federal emergency managers, scientific communities, and the general public; coordinate field investigations of earth scientists; serve as a data collection point for technical and non-technical observations; announce physical clearinghouse meetings; and for archiving data from past geologic-hazard events.

- The UGS participated in the 2012 Great Utah ShakeOut earthquake exercise with the Utah Department of Emergency Management by activating our Emergency Operations Center and sending teams of geologists to the field to investigate and report on simulated geologic effects of a M 7 earthquake on the Salt Lake City segment of the WFZ.

- The UGS participated as a member of the Utah Earthquake Program with the Utah Division of Emergency Management and University of Utah Seismograph Stations to coordinate earthquake-related research, outreach, and training in Utah.

REPORTS PUBLISHED

We have posted the results of the 2012 working group meetings on the UGS website at http://geology.utah.gov/ghp/workgroups/index.htm. In 2013, the UGS anticipates publishing Special Study reports of the ongoing paleoseismic investigations for the Salt Lake City segment of the WFZ/West Valley fault zone, the Nephi segment of the WFZ, and the Fort Pearce section of the Washington fault zone.

Reports in support of the earthquake working groups and NEHRP-funded projects published by the UGS or written by UGS authors in 2010 to 2012 are listed below:

- Bowman, S.D., 2011, New Utah historical geologic data resources - what is available and where to find it [abs.]: Geological Society of America Abstracts with Programs, v. 43, no. 4, p. 74, available online at http://gsa.confex.com/gsa/2011RM/finalprogram/abstract_187305.htm.

- Bowman, S.D, Young, B.W., and Unger, C.D., 2011, Paleoseismology of Utah, Volume 21 - Compilation of 1982-83 seismic safety investigation reports of eight SCS dams in southwestern Utah (Hurricane and Washington fault zones) and low-sun-angle aerial photography, Washington and Iron Counties, Utah, and Mohave County, Arizona: Utah Geological Survey Open-File Report 583, 4 p., 6 DVD set, available online at http://geology.utah.gov/ghp/consultants/paleoseismic_series.htm.

- Bowman, S.D., 2012, Utah Geological Survey Geologic Data Preservation Project and new geologic data resources, *in* Hylland, M.D., and Harty, K.M., editors, Selected topics in engineering and environmental geology in Utah: Utah Geological Association Publication 41, p. 195–207, DVD.

- Bowman, S.D., 2012, Utah Geological Survey Geologic Data Preservation Project and new geologic data resources [abs.]: Association of Environmental and Engineering Geologists, AEG News, v. 55, Program with Abstracts, 2012 Annual Meeting, p. 47.

- Castleton, J.J., Elliott, A.H., and McDonald, G.N., 2011, Geologic hazards of the Magna quadrangle, Salt Lake County, Utah: Utah Geological Survey Special Study 137, 9 plates, GIS files, DVD, available online at http://geology.utah.gov/online/ss/ss-137/ss-137.pdf and http://geology.utah.gov/maps/geohazmap/saltlake.htm.

- DuRoss, C.B., Personius, S.F., Crone, A.J., McDonald, G.N., and Briggs, R., 2010, Late Holocene earthquake history of the Brigham City segment of the Wasatch fault zone at the Hansen Canyon, Kotter Canyon, and Pearsons Canyon trench sites, Box Elder County, Utah: Final Technical Report to the U.S. Geological Survey, National Earthquake Hazards Reduction Program, Award no. 08HQGR0082, 40 p., 3 plates, available online at http://earthquake.usgs.gov/research/external/reports/08HQGR0082.pdf.

- DuRoss, C.B., and Pankow, K.L., 2010, Liquefaction in the 15 April 2010 M_w 4.5 Randolph, Utah, Earthquake: Abstract S51B-1931 presented at 2010 Fall Meeting of the American Geophysical Union, San Francisco, California.

- DuRoss, C.B., Crone, A.J., Hylland, M.D., McDonald, G.N., Personius, S.P., Gold, R.D., and King, B.D., 2010, Multiple Holocene surface-rupturing earthquakes on the East Bench fault, Salt Lake City, Utah: Geological Society of America Abstracts with Programs, v. 42, no. 5, p. 595.

- DuRoss, C.B., 2011, Liquefaction in the April 15, 2010, M 4.5 Randolph earthquake: Utah Geological Survey, Survey Notes, v. 31, no. 1, p. 7, available online at http://geology.utah.gov/surveynotes/snt43-1.pdf.

- DuRoss, C.B., dePolo, C.M., Koehler, R.D., Bowman, S.D., McDonald, G.N., and Shaw, L.M., 2011, Immediate scientific response to the 2008 Wells, Nevada, earthquake, *in* dePolo, C.M., and LaPointe, D.D., editors, The 21 February 2008 Mw 6.0 Wells, Nevada earthquake - a compendium of earthquake-related investigations prepared by the University of Nevada, Reno: Nevada Bureau of Mines and Geology Special Publication 36, p. 415-425, available online at http://www.nbmg.unr.edu/Pubs/sp/sp36/index.html.

- 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, Utah: Bulletin of the Seismological Society of America, v. 101, no. 6, p. 2765-2781.

- 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, Utah [abs.]: Seismological Research Letters, v. 82, no. 2, p. 342.

- DuRoss, C.B., Crone, A.J., Personius, S.F., McDonald, G.N., Hylland, M.D., Briggs, R.W., Lund, W.R., and Mahan, S.A., 2011, Overview of recent paleoseismic studies on the Brigham City, Weber, and Salt Lake City segments of the Wasatch fault zone, Utah [abs.]: Geological Society of America Abstracts with Programs, v. 43, no. 4, p. 7, available online at http://gsa.confex.com/gsa/2011RM/finalprogram/abstract_187337.htm.

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DATA AVAILABILITY

We have posted the results of the 2010 working group meetings on the UGS website at http://geology.utah.gov/ghp/workgroups/index.htm. Agendas and summaries for each working group meeting are also available in appendix 2 and 3, respectively. Individual web pages for each earthquake working group, including meeting agendas, summaries, and presentations, are available at:

- Quaternary Fault Parameters Working Group (http://geology.utah.gov/ghp/workgroups/uqfpwg.htm)
- Liquefaction Advisory Group (http://geology.utah.gov/ghp/workgroups/ulag.htm)
- Ground Shaking Working Group (http://geology.utah.gov/ghp/workgroups/gswg.htm)
- Working Group on Utah Earthquake Probabilities (http://geology.utah.gov/ghp/workgroups/wguep.htm)

The UGS Geologic Hazards Program revised significant portions of its web page (http://geology.utah.gov/ghp/index.htm) by making information and publications easier to locate, and in scanning documents and maps not previously in digital format. The current version of the WFCVM, version 3c, is available on the UGS website (http://geology.utah.gov/ghp/consultants/geophysical_data/cvm.htm). The shallow-shear-wave velocity (Vs30), deep-basin-structure, and landslide geotechnical shear-strength databases are currently available from Greg McDonald, UGS at (801) 537-3383, email: gregmcdonald@utah.gov.

Geologic Data Preservation and the UGS GeoData Archive System

The UGS has collected unpublished reports, maps, memorandums, field notes, and other geologic-hazard and engineering-geology (including fault evaluation and other paleoseismic-related) documents since formation of the UGS Site Investigation Section (now Geologic Hazards Program) in 1980. Few copies were ever produced of most of the documents in the collection. These documents are now used in geologic-hazard investigations, geologic and engineering-geologic mapping projects, during emergency-response activities, and in response to public inquiries. In 2010, the UGS started digital scanning and metadata creation on these documents and developed the GeoData Archive System (https://geodata.geology.utah.gov) to manage the collection as part of ongoing USGS/UGS-funded National Geological and Geophysical Data Preservation Program (NGGDPP) projects. The system currently includes most of the fault evaluation reports submitted to Salt Lake County as part of development permit applications. The UGS updates the system with new reports and documents as they become available.

In addition, the UGS through various NGGDPP projects, has scanned and made available to the public, over 67,000 aerial photographs of Utah taken between 1935 and 2004. Over 2270 low-sun-angle aerial photographs of the Wasatch, Washington, and Hurricane fault zones are part of this collection, and include the best pre-development aerial photographs taken of these fault zones. The UGS Aerial Imagery Collection may be accessed at http://geology.utah.gov/databases/imagery/.

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Table 1 – Earthquake Working Group Coordinators and Chairs		
Working Group	**UGS Coordinator**	**Chair**
Utah Quaternary Fault Parameters Working Group	Bill Lund	Bill Lund
Utah Liquefaction Advisory Group	Mike Hylland	Dr. Steve Bartlett, University of Utah
Ground Shaking Working Group	Greg McDonald	Ivan Wong, URS Corporation
Working Group on Utah Earthquake Probabilities	Bill Lund	Ivan Wong, URS Corporation

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APPENDIX 1 – 2012 UTAH EARTHQUAKE WORKING GROUP MEMBERS

Utah Earthquake Working Groups

Steve Bowman, Utah Geological Survey, Principal Investigator
Pam Perri, Utah Geological Survey, Travel and Catering Coordinator

Utah Quaternary Fault Parameters Working Group (UQFPWG)

William Lund, Utah Geological Survey, Chair
Rich Briggs, U.S. Geological Survey
Tony Crone, U.S. Geological Survey
Chris DuRoss, Utah Geological Survey
Kathy Haller, U.S. Geological Survey
Ron Harris, Brigham Young University
Daniel Horns, Utah Valley University
Mike Hylland, Utah Geological Survey
Susan Olig, URS Corporation
Jim Pechmann, University of Utah Seismograph Stations
Steve Personius, U.S. Geological Survey
Mark Petersen, U.S. Geological Survey
Lucy Piety, U.S. Bureau of Reclamation
Bob Smith, University of Utah Geology & Geophysics
Ivan Wong, URS Corporation

Ground Shaking Working Group (GSWG)

Ivan Wong, URS Corporation, Chair
Greg McDonald, Utah Geological Survey, Coordinator
Walter Arabasz, University of Utah Seismograph Stations
Rich Briggs, U.S. Geological Survey
Tony Crone, U.S. Geological Survey
Keith Koper, University of Utah Seismograph Stations
Qiming Liu, University of California, Santa Barbara
Morgan Moschetti, U.S. Geological Survey
Jim Pechmann, University of Utah Seismograph Stations
Kris Pankow, University of Utah Seismograph Stations
Mark Petersen, U.S. Geological Survey
Bob Smith, University of Utah Geology & Geophysics

Utah Liquefaction Advisory Group (ULAG)

Steve Bartlett, University of Utah, Chair
Mike Hylland, Utah Geological Survey, Coordinator
Loren Anderson, Utah State University
Jim Bay, Utah State University
Rich Briggs, U.S. Geological Survey
Ryan Cole, Gerhart Cole, Inc.
Tony Crone, U.S. Geological Survey
Travis Gerber, URS Corporation
Grant Gummow, Utah Department of Transportation
Jim Higbee, Utah Department of Transportation
John Rice, Utah State University
Kyle Rollins, Brigham Young University
David Simon, Simon Bymaster, Inc.
Bill Turner, Earthtec
Les Youd, Brigham Young University

Working Group on Utah Earthquake Probabilities (WGUEP)

Ivan Wong, URS Corporation, Chair
Bill Lund, Utah Geological Survey, Coordinator
Steve Bowman, Utah Geological Survey, Liaison
Walter Arabasz, University of Utah Seismograph Stations
Rich Briggs, U.S. Geological Survey
Tony Crone, U.S. Geological Survey
Chris DuRoss, Utah Geological Survey
Mike Hylland, Utah Geological Survey
Nico Luco, U.S. Geological Survey
Susan Olig, URS Corporation
Jim Pechmann, University of Utah Seismograph Stations
Steve Personius, U.S. Geological Survey
Mark Petersen, U.S. Geological Survey
Dave Schwartz, U.S. Geological Survey
Bob Smith, University of Utah Geology & Geophysics
Patricia Thomas, URS Corporation

APPENDIX 2 – UTAH EARTHQUAKE WORKING GROUP MEETING AGENDAS
Utah Quaternary Fault Parameters Working Group

AGENDA

QUATERNARY FAULT PARAMETERS WORKING GROUP
Tuesday, February 9, 2010
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

7:00 Continental breakfast

7:30 Introduction, overview of meeting, review of last year's activities

8:00 Technical presentations of work completed or in progress
- 8:00 – Brigham City segment, trenching update; Tony Crone/Steve Personius, USGS
- 8:20 – Washington fault northern segment, trenching update; Bill Lund/Tyler Knudsen, UGS
- 8:40 – Washington fault Southern Beltway trenching investigation; Dave Simon, Simon • Bymaster, Inc.
- 9:00 – U.S. Bureau of Reclamation Utah fault studies update; Larry Anderson, USBR
- 9:20 – Bear River fault zone, trenching update; Suzanne Hecker, USGS
- 9:40 – East Cache fault zone, trenching update; Jim Evans, USU

10:00 Break

10:20 Technical presentations of work completed or in progress
- 10:20 – Salt Lake City segment/West Valley fault zone investigation, progress report; Mike Hylland, UGS
- 10:40 – Working Group on Utah Earthquake Probabilities; Ivan Wong, URS/Bill Lund, UGS

11:00 Technical discussion item
Revised Weber segment slip-rate and recurrence-interval estimates; Chris DuRoss, UGS/Steve Personius, USGS

12:00 Lunch

1:00 Technical discussion item
Revised Weber segment slip-rate and recurrence-interval estimates – discussion

1:30 UQFPWG 2011 fault study priorities (see table 1 for 2010 priority list; see table 2 for original UQFPWG fault priority list)

2:30 Adjourn

Table 1. *UQFPWG 2010 highest priority list of Quaternary faults/fault segments requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level, and status of current paleoseismic investigations on all Utah priority faults/fault segments. Yellow highlights changes in past year; green indicates related non-paleoseismic study.*

2010 Highest Priority Faults/Fault Sections For Study			
Fault/Fault Section	**Priority**	**Investigation Status**	**Investigating Institution**
Northern Salt Lake City segment WFZ	1	Study funded (NEHRP)	UGS/USGS
West Valley fault zone	2	Study funded (NEHRP)	UGS/USGS
Penultimate event Provo segment WFZ	3	Trench site reconnaissance	UGS
Washington fault	4	Two trenching investigations	UGS/Simon•Bymaster
Rozelle section, Great Salt Lake fault	5	No activity	
Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Cedar City-Parowan monocline/ Paragonah fault	10	No activity	
Enoch graben	11	Earth fissure study	UGS
Clarkston fault	13	No activity	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Bear River fault zone	2007	Trenching study	USGS
Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Nephi segment WFZ	1	UGS Special Study 124/USGS Map 2966/UVSC study ongoing	UGS/USGS/UVSC
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Ongoing	UUGG
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley faults	14	Ongoing	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan	16	UGS Map 229	UGS
Brigham City section – most recent event	2007	Ongoing	UGS/USGS

Table 2. *Original priority list of Quaternary faults/fault segments identified by the UQFPWG as requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level.*

Fault/Fault Segment	Original UQFPWG Priority (2005)
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	Added 2007
Brigham City segment WFZ – most recent event	Added 2007
Carrington fault (Great Salt Lake)	Added 2007
Provo segment – penultimate event	Added 2007
Rozelle section – Great Salt lake Fault	Added 2007

AGENDA

QUATERNARY FAULT PARAMETERS WORKING GROUP
Tuesday, February 15, 2011
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

7:30 Continental breakfast

8:00 Introduction, overview of meeting, review of last year's activities

8:15 Technical presentations of work completed or in progress
- 8:15 – Salt Lake City segment trenching update; Chris DuRoss, UGS
- 8:45 – West Valley fault zone trenching update; Mike Hylland, UGS
- 9:15 – Nephi segment trenching update; Danny Horns, UVU
- 9:45 – Joes Valley fault zone update; Lucy Piety, USBR

10:15 Break

10:30 Technical presentations of work completed or in progress
- 10:30 – East Canyon & East of East Canyon (Main Canyon) fault updates; Lucy Piety, USBR
- 11:00 – Interactive Utah Quaternary fault map; Cory Unger and Mike Hylland, UGS
- 11:30 – East Cache fault zone trenching update; Jim Evans, USU

12:00 Lunch

1:00 Technical presentations of work completed or in progress
- 1:00 – Utah Lake faults study update; Dave Dinter, UU
- 1:20 – Working Group on Utah Earthquake Probabilities update; Ivan Wong, URS and Bill Lund, UGS
- 1:50 – Revised Wasatch fault zone earthquake timing and recurrence; Chris DuRoss, UGS
- 2:40 – Implementation: The third dimension of Seismic Hazard Mitigation; Ron Harris, BYU

3:00 Break

3:15 Technical discussion items
Recommendations (?) to the USGS for the National Quaternary Fault and Fold Map regarding the Joes Valley fault zone and the East Canyon & East of East Canyon (Main Canyon) faults – discussion

3:45 UQFPWG 2012 fault study priorities (see table 1 for 2011 priority list; see table 2 for original UQFPWG fault priority list)

4:45 Adjourn

Table 1. *UQFPWG 2011 highest priority list of Quaternary faults/fault segments requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level, and status of current paleoseismic investigations on all Utah priority faults/fault segments.*

2011 Highest Priority Faults/Fault Sections For Study			
Fault/Fault Section	**Priority**	**Investigation Status**	**Investigating Institution**
Warm Springs fault/East Bench fault subsurface geometry and connection	1	No activity	
Penultimate event Provo segment WFZ	2	Trench site reconnaissance	UGS
Long-term earthquake record Nephi segment WFZ	3	No activity	
Washington fault	4	Two trenching investigations	UGS/Simon-Bymaster
Mid- to late-Holocene earthquake chronology southern part Weber segment WFZ	5	No activity	
Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Cedar City-Parowan monocline/Paragonah fault	10	No activity	
Enoch graben	11	No activity	
Clarkston fault	13	No activity	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault	2007	No activity	
Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 UVU study ongoing	UGS/USGS/UVU
West Valley fault zone	2	Study funded for 2010	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Study funded 2009	UUGG
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley faults	14	Ongoing	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north end	2009	Study funded for 2010	UGS/USGS

Table 2. *Priority list of Quaternary faults/fault segments identified by the UQFPWG as requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level.*

Fault/Fault Segment	**Original UQFPWG Priority (2005)**
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan segment WFZ	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	Added 2007
Brigham City segment WFZ – most recent event	Added 2007
Carrington fault (Great Salt Lake)	Added 2007
Provo segment WFZ – penultimate event	Added 2007
Rozelle section – Great Salt Lake Fault	Added 2007
Salt Lake City segment WFZ – northern part	Added 2009

AGENDA

QUATERNARY FAULT PARAMETERS WORKING GROUP
Wednesday, February 15, 2012
Utah Department of Natural Resources Building, Rooms 1040–1050 (1st Floor)
1594 West North Temple, Salt Lake City

8:00 Continental breakfast

8:30 Introduction, overview of meeting, review of last year's activities

8:40 Technical presentations of work completed or in progress
- 8:40 – Penrose Drive site trenching update; Chris DuRoss, UGS
- 9:00 – West Valley fault zone trenching update; Mike Hylland, UGS
- 9:20 – Utah Lake study update; Ron Harris; BYU
- 9:40 – Lake Powell Pipeline Hurricane fault crossing investigation; Dean Ostenna, Fugro, Inc.

10:00 Break

10:20 Technical presentations of work completed or in progress
- 10:20 – Blue Castle nuclear power plant seismic-hazard investigation; Dean Ostenna, Fugro, Inc.
- 10:40 – Paunsaugunt fault investigation; Bob Kirkham [written summary provided]
- 11:00 – New UGS Nephi segment trenching project; Chris DuRoss, UGS
- 11:20 – Update on new Wasatch fault earthquake-timing and recurrence-interval data; Chris DuRoss, UGS
- 11:40 – Updated GPS analysis for the Wasatch Front; Christine Puskas, Univ. of Colorado

12:00 Lunch

1:00 Technical presentations of work completed or in progress
- 1:00 – Working Group on Utah Earthquake Probabilities update; Ivan Wong, URS/Bill Lund, UGS
- 1:20 – Report on Basin and Range Province Earthquake Working Group II; Bill Lund, UGS

1:40 Technical discussion item
- 1:40 – East Cache fault zone; Bill Lund, UGS

2:00 UQFPWG 2013 fault study priorities (see table 1 for 2012 priority list; see table 2 for original UQFPWG fault priority list)

3:00 Break

3:20 UQFPWG 2013 fault study priorities continued/meeting wrap up.

3:45 Adjourn

Table 1. *UQFPWG 2012 list of highest priority Quaternary faults/fault segments requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level, and status of current paleoseismic investigations on all currently identified Utah priority faults/fault segments.*

2012 Highest Priority Faults/Fault Sections For Study		
Fault/Fault Section[1]	**Investigation Status**	**Investigating Institution[2]**
Brigham City segment WFZ rupture extent (north and south ends)	No activity	
Long-term earthquake record Nephi segment WFZ	NEHRP grant awarded	UGS
Long-term earthquake record northern Provo segment WFZ	No activity	
Long-term earthquake record southern Weber segment WFZ	No activity	
Penultimate event Provo segment WFZ	Trench site reconnaissance	UGS
West Valley fault zone – Taylorsville fault	No activity	

Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[3]	13	Black and others (2000)	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault[4]	2007	No activity	
Warm Springs fault/East Bench fault subsurface geometry and connection[4]	2010	No activity	
Hansel Valley fault[3]	2011	Fault reconnaissance	UGS

Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 UVU study ongoing	UGS/USGS/UVU
West Valley fault zone	2	Study funded 2010	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Study funded 2009	UUGG
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley faults	14	Ongoing	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north end	2009	Study funded 2010	UGS/USGS

[1]Listed in alphabetical, not priority order.
[2]UGS (Utah Geological Survey), USU (Utah State University), USGS (U.S. Geological Survey), UVU (Utah Valley University), UUGG (University of Utah Department of Geology & Geophysics), USBR (U.S. Bureau of Reclamation).
[3]Earthquake source on the USGS National Seismic Hazard Maps.
[4]Previous UQFPWG highest priority fault/fault segment.

Table 2. *Priority list of Quaternary faults/fault segments identified by the UQFPWG as requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level.*

Fault/Fault Segment	Original UQFPWG Priority (2005)
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan segment WFZ	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	2007
Brigham City segment WFZ – most recent event	2007
Carrington fault (Great Salt Lake)	2007
Provo segment WFZ – penultimate event	2007
Rozelle section – East Great Salt Lake fault	2007
Salt Lake City segment WFZ – northern part	2009
Warm Springs fault/East Bench fault subsurface geometry and connection	2010
Brigham City segment WFZ rupture extent (north and south ends)	2011
Long-term earthquake record northern Provo segment WFZ	2011
West Valley fault zone – Taylorsville fault	2011

AGENDA
UTAH GROUND SHAKING WORKING GROUP

Monday, February 8, 2010
Utah Department of Natural Resources Building, Room 2000
1594 W. North Temple, Salt Lake City

7:00 – 7:30	Continental Breakfast	
7:30 – 7:45	Introduction Overview of Meeting Review of Last Year's Priorities	Ivan Wong
7:45 – 8:00	Analysis of ANSS Data for Stress Drop and Kappa	Ivan Wong
8:00 – 8:15	Sonic Log Analyses for the Wasatch Front CVM	Jim Pechmann
8:15 – 8:30	Update on Modifications to Community Velocity Model (CVM)	Harold Magistrale
8:30 – 9:00	Wasatch Front CVM - Versions in Use by Modelers/Effects on Results - Distribution of Model - Future Updates	Greg McDonald
9:00 – 11:00	Presentation/Discussion of Different Wasatch Front Ground Motion Models	
9:00 – 9:10	- USGS Plans for Analysis of the CVM	Morgan Moschetti/ Mark Petersen
9:10 – 9:20	- 3D Nonlinear Earthquake Ground Motion Simulation in the Salt Lake Basin Using the Wasatch Front CVM	Jacobo Bielak
9:20 – 9:50	- Ground Motions in Salt Lake Basin from Dynamic Modeling of a **M** 7 Earthquake on the Wasatch Fault	Ralph Archuleta/ Bob Smith
9:50 – 10:00	Break	
10:00 – 10:45	- 3D Nonlinear Broadband Ground Motion Predictions for **M** 7 Earthquakes on the Salt Lake City Segment of the Wasatch Fault Using Dynamic Source Models	Kim Olsen/Daniel Roten
10:45 – 11:00	- Modeling Near-Surface Effects	Ivan Wong
11:00 – 12:00	USGS perspective - Comparison of Models/Differences - Applicability for Urban Hazard Maps, Direction of Modeling, and Priorities for Future Research	Mark Petersen
12:00	Adjourn	

<u>Ground Shaking Working Group-Membership</u>

Ivan Wong, URS Corporation, Facilitator
Greg McDonald, UGS
Mark Petersen, USGS
Walter Arabasz, UUSS
Jim Pechmann, UUSS
Kyle Rollins, BYUCE
Wulung Chang, UUGG
Relu Berlacu, UUSS

Kris Pankow, UUSS
Bob Smith, UUSS
Kim Olsen, SDSU
Harold Magistrale, SDSU
Bill Stephenson, USGS
Jim Bay, USUCEE

Guests
Jacobo Bielak, Carnegie-Mellon
Morgan Moschetti, USGS
Ralph Archuleta, UCSB
Daniel Roten, SDSU
Tony Crone, USGS

AGENDA
UTAH GROUND SHAKING WORKING GROUP

Monday, February 14, 2011
Utah Department of Natural Resources Building, Room 2000
1594 W. North Temple, Salt Lake City

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Introduction Overview of Meeting Review of Last Year's Priorities	Ivan Wong
8:15 – 8:45	Analyses of Earthquake Source, Path, and Site Parameters From ANSS Data Along the Wasatch Front, Utah	Ivan Wong/ Jim Pechmann
8:45 – 9:15	3D Nonlinear Earthquake Ground Motion Simulation in the Salt Lake Basin Using the Wasatch Front CVM	Jacobo Bielak/ Ricardo Taborda
9:15 – 9:45	Characterization of Shallow S-Wave Velocity Structures in Southwestern Utah	Kris Pankow
9:45 – 10:00	Break	
10:00 – 10:30	Ground Motions in the Salt Lake Basin from Dynamic Modeling of a M 7 Earthquake on the Wasatch Fault	Ralph Archuleta/ Bob Smith
10:30 – 11:00	Approximate Linear-to-Nonlinear Correction Factors for Broadband Synthetics Computed for the Salt Lake Valley	Kim Olsen
11:00 – 11:30	Kinematic Modeling using the Wasatch Front CVM/Evaluation of possible upgrades to the CVM	Morgan Moschetti/ Mark Petersen
11:30 – 12:00	Questions/Discussion of Technical Presentations/Preview of Afternoon Session	All
12:00 – 1:00	Lunch	
1:00 – 5:00	USGS Wasatch Front Urban Hazard Maps Roundtable Discussion General Topics - Evaluation of current modeling efforts; comparison of input parameters, validation studies, current results - Possible improvements to CVM/input parameters - What are the model differences/similarities - Applicability of each model to Urban Hazard Maps - Incorporation of components from different models into maps - Addressing near-surface site response Urban Hazard Maps Final Products - Formats - User interface - Distribution - Updates	Mark Petersen/ Ivan Wong
5:00	Adjourn	

Ground Shaking Working Group-Membership
Ivan Wong, URS Corporation, Facilitator
Greg McDonald, UGS, Liasion
Mark Petersen, USGS
Walter Arabasz, UUSS
Jim Pechmann, UUSS
Kris Pankow, UUSS
Bob Smith, UUSS
Keith Koper, UUSS
Harold Magistrale, SDSU
Bill Stephenson, USGS
Jim Bay, USUCEE
Relu Berlacu, UUSS
Kyle Rollins, BYUCE
Wulung Chang, UUGG

Guests
Jacobo Bielak, Carnegie-Mellon
Morgan Moschetti, USGS
Ralph Archuleta, UCSB
Tony Crone, USGS
Leo Ramirez, USGS
Mike Thorne, UUSS
Kim Olsen, SDSU
Ricardo Taborda, CMU

AGENDA
UTAH GROUND SHAKING WORKING GROUP

Tuesday, February 14, 2012
Utah Department of Natural Resources Building, Room 1040-1050
1594 W. North Temple, Salt Lake City

8:00 – 8:30	Continental Breakfast	
8:30 – 8:50	Introduction Overview of this year's meeting Review of last year's priorities	Ivan Wong
8:50 – 9:10	Review of Ground Motion Predictions from 0-10 Hz for M7 on the Salt Lake City Segment	Kim Olsen
9:10 – 9:30	Curved Fault Dynamic Rupture Model of Wasatch Fault Salt Lake City Segment	Qiming Liu
9:30 – 9:50	Earthquake Ground Motion Modeling with Kinematic Source Models	Morgan Moschetti
9:50 – 10:10	Review of 3-D Nonlinear Ground Motion Modeling	Jacobo Bielak
10:10 – 10:30	Break	
10:30 – 10:45	Instrumentally Recorded Ground Motions M3 or Greater in the Utah Region since 2000	Kris Pankow
10:45 – 12:00	Questions/Discussion of Technical Presentations/Preview of Afternoon Session	
12:00 – 1:00	Lunch	
1:00 – 4:00	USGS Wasatch Front Urban Seismic Hazard Maps (USHMs) Discussion: Possible Topics - Review what components are needed for the USHMs - Evaluate/compare different models; input parameters, validation studies, results - Compare model differences/similarities and evaluate the applicability of each model to the USHMs; what elements from each should be used - Evaluate how to incorporate components from different models into the USHMs - Determine how to address higher frequencies - Determine how to address near-surface site response - Assess whether or not the maps should be extended beyond SLV to the north and/or south - Consider what components may have been left out or can be improved upon - Decide whether to meet in 2013 or wait until 2014 - Evaluate USHM Final Products o Formats	Mark Petersen/Ivan Wong

- o User interface
- o Distribution
- o Updates

Ground Shaking Working Group Membership
Ivan Wong, URS Corporation, Facilitator
Greg McDonald, UGS, Liasion
Mark Petersen, USGS
Jim Pechmann, UUSS
Kris Pankow, UUSS
Bob Smith, UUSS
Keith Koper, UUSS
Harold Magistrale, FM Global
Bill Stephenson, USGS
Jim Bay, USUCEE
Relu Berlacu, UUSS
Kyle Rollins, BYUCE
Kim Olsen, SDSU
Jacobo Bielak, Carnegie-Mellon

Guests
Qiming Liu, UCSB
Morgan Moschetti, USGS
Ralph Archuleta, UCSB
Leo Ramirez, USGS
Mike Thorne, UUSS
Tony Crone, USGS
Ricardo Taborda, Carnegie-Mellon
Christine Puskas, UUGG
Jamie Farrell, UUGG
Alan Cannady, UUGG
Fred Massin, UUGG

AGENDA

UTAH LIQUEFACTION ADVISORY GROUP

Monday, February 8th, 2010
Utah Department of Natural Resources Building
1594 W. North Temple, Salt Lake City

1:00 pm	Introduction – Mike Hylland
1:10	ULAG Overview and Progress – Steven Bartlett
	Technical presentations of work completed
1:25	Daniel Hinckley, U of U
	• Settlement maps
1:45	Daniel Gillins, U of U
	• Mapping techniques for under-sampled units
2:15	Break
2:25	Review of 2009 Proposal and Panel Suggestions – Steven Bartlett
2:35	Listing of 2010 NEHRP focus areas
	• Partnerships
	o Weber Basin Water Conservancy District
	o Utah Division of Homeland Security
	o FEMA
	o Salt Lake City
	• Future Mapping
	• Performance-Based Hazard Ordinance
	• Collaboration with Utah Quaternary Fault Parameters Working Group
	o Warm Springs Fault
	o Library Block
	o 2^{nd} East to 10^{th} East Line
4:00	Adjourn

AGENDA

UTAH LIQUEFACTION ADVISORY GROUP

Tuesday, February 15th, 2011
Utah Department of Natural Resources Building
1594 W. North Temple, Salt Lake City

1:00 pm	Introduction – Mike Hylland, UGS
1:10	ULAG Overview and Progress – Steven Bartlett, U of U
	Technical presentations:
1:25	Liquefaction in the M 4.5 Randolph, Utah earthquake – Chris DuRoss, UGS
1:45	Mapping of Weber County – Daniel Gillins, U of U
2:30	Break
2:45	Review of 2010 Proposal and Panel Suggestions – Steven Bartlett
3:00	Development and Prioritization of 2011 NEHRP focus areas

- New Initiatives Beyond Mapping
- Future Mapping Efforts
- Partnerships
  - Weber Basin Water Conservancy District
  - Utah Division of Homeland Security
  - FEMA
  - Salt Lake City
- Collaboration with Utah Quaternary Fault Parameters Working Group
  - Warm Springs Fault
  - Library Block
  - Other work downtown

4:30 Adjourn

AGENDA

UTAH LIQUEFACTION ADVISORY GROUP

2012 Meeting Announcement
Utah Department of Natural Resources Building
1594 W. North Temple, Salt Lake City

Dear ULAG member:

This is to inform you that the Utah Liquefaction Advisory Group (ULAG) will not be meeting during the 2012 Utah Earthquake Working Group meetings sponsored by the Utah Geological Survey, primarily due to the lack of funding for proposals submitted over the past several years. Over the coming year, Steve Bartlett, Steve Bowman, and I will be concentrating our efforts on facilitating the goals identified at the 2011 meeting, including publication of the Salt Lake County liquefaction hazard maps, development of a model liquefaction ordinance, development of a workshop for local governments addressing implementation of the liquefaction hazard maps, and identifying keynote speakers for education/tech transfer at the 2013 ULAG meeting. If you would like to help with any of these tasks, please let me know.

As always, if you are interested in attending any of the other 2012 Utah Earthquake Working Group meetings as an observer, you are more than welcome to do so. The Ground Shaking Working Group will meet on Feb. 14 (8:30 a.m. – 5:00 p.m.), the Quaternary Fault Parameters Working Group will meet on Feb. 15 (8:30 a.m. – 5:00 p.m.), and the Working Group on Utah Earthquake Probabilities will meet on Feb. 16 (8:30 a.m. – 5:00 p.m.) and Feb. 17 (8:30 a.m. – 3:00 p.m.).

Best regards,

Mike Hylland
Utah Geological Survey Liaison

AGENDA
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Wednesday/Thursday, February 10 & 11, 2010
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

10 February 2010

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome and Introductions	Bill Lund
8:15 – 9:00	Purpose, Tentative Scope of Work, SSHAC Process, and Schedule	Ivan Wong
9:00 – 9:30	Overview of UCERF2	Mark Petersen
9:30 – 10:15	Issues Associated with UCERF2	David Schwartz
10:15 – 10:30	Break	
10:30 – 11:00	Discussion on UCERF2	Mark Petersen/ David Schwartz
11:00 – 12:00	Overview of Wasatch Fault	Chris DuRoss
12:00 – 1:00	Lunch	
1:00 – 2:00	Overview of Forecast Model Inputs	Ivan Wong
2:00 – 3:00	Overview of Utah Quaternary Fault Working Group Model	Bill Lund
3:00 – 3:15	Break	
3:15 – 4:15	Review of Wasatch Time-Dependent Probabilities	Susan Olig
4:15 – 5:00	Discussion	
5:00	Adjourn	

11 February 2010

7:30 – 8:00	Continental Breakfast	
8:00 – 9:00	Overview of Seismicity Catalog	Walter Arabasz/Jim Pechmann
9:00 – 9:30	Incorporation of Background Seismicity into Forecast	Walter Arabasz/Jim Pechmann
9:30 – 9:45	Break	
9:45 – 10:45	Overview of Geodetic Data	Bob Smith
10:45 – 11:30	Incorporation of Geodetic Rates into Forecast	Bob Smith
11:30 – 12:30	Lunch	
12:30 – 3:00	Issues (integration of geodetic data, segmentation, multi-segment rupture, recurrence models, etc.)	Ivan Wong
3:00 – 3:15	Break	
3:15 – 4:00	Path Forward	All
4:00	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

WORKING GROUP ON UTAH EARTHQUKE PROBABILITIES
MEETING AGENDA
Wednesday & Thursday, July 21/22, 2010
Utah Department of Natural Resources Building, Room 2000
1594 West North Temple, Salt Lake City

Wednesday July 21

7:30 a.m.	Continental breakfast
8:00 a.m.	Methodology Summary - Use of OxCal and MATLAB to refine earthquake timing and recurrence for the five central Wasatch fault segments – Chris DuRoss
8:30 a.m.	OxCal earthquake timing and MATLAB recurrence interval models for the five central Wasatch fault segments (earthquake pdfs, individual intervals between events, average segment recurrence intervals, MRE timing) – Chris DuRoss, Steve Personius, Tony Crone, Susan Olig
10:00 a.m.	Break
10:30 a.m.	OxCal earthquake timing and MATLAB recurrence interval models for the five central Wasatch fault segments continued
12:00 p.m.	Lunch
1:00 p.m.	Summary and discussion Wasatch fault earthquake timing and recurrence intervals – Chris DuRoss
2:00 p.m.	Earthquake timing and slip-rate information for Wasatch fault end segments – Mike Hylland
4:00 p.m.	Summary and discussion of Wasatch fault end segment data - select end segment parameters for probability model – Mike Hylland
4:30 p.m.	Wrap up – Ivan Wong
5:00 p.m.	Adjourn

Thursday July 22

7:00 a.m.	Continental breakfast
7:30 a.m.	Introduction to rupture scenario models - Bay Area faults vs. Wasatch fault - David Schwartz
8:00 a.m.	Presentation Wasatch fault strawman rupture scenario models – David Schwartz, Chris DuRoss
10:00 a.m.	Break

10:30 a.m.	Final rupture scenario model selection and weighting by working group members - moderator David Schwartz
12:00 p.m.	Lunch
1:00 p.m.	Other faults in the Wasatch Front study region – how many, how big, how fast – Bill Lund
2:30 p.m.	The way forward – Ivan Wong
3:00 p.m.	Adjourn

AGENDA

WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Wednesday/Thursday, December 1 & 2, 2010
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

1 December 2010

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome	Bill
8:15 – 8:30	Overview of Agenda	Ivan
8:30 – 10:00	Report from Paleoseismology Subgroup – Revised Earthquake Timing, Recurrence, and Strawman Rupture Scenarios for Central Wasatch Fault	Chris
10:00 – 10:15	Break	Chris
10:15 – 12:00	Discussion of Rupture Scenarios and Final Model Selection and Weighting	Chris
12:00 – 1:00	Lunch	
1:00 – 1:30	Final Slip Rates for Wasatch Fault End Segments	Mike
1:30 – 2:00	Update on Salt Lake City Fault Trenches	Chris
2:00 – 2:45	Update on West Valley Fault Zone Trenches	Mike
2:45 – 3:00	Break	
3:00 – 4:00	Earthquake Recurrence Models	Ivan/Nico
4:00 – 5:00	General Discussion	Ivan

2 December 2010

7:30 – 8:00	Continental Breakfast	
8:00 – 9:00	Conversion of Horizontal Geodetic Extension Rates to Fault Dip-Slip Rates	Mark
9:00 – 9:30	Mmax Calculations	Susan
9:30 – 10:30	Moment Balancing	Mark
10:30 – 10:45	Break	
10:45 – 11:30	Time-Dependent Recurrence for Great Salt Lake Fault?	Jim
11:30 – 12:00	Other Faults that Should be Time-Dependent?	Bill
12:00 – 1:00	Lunch	
1:00 – 1:30	Other Faults on the Bubble	Bill
1:30 – 2:00	Update on Wasatch Front Background Earthquakes	Jim/Walter
2:00 – 3:00	Discussion and Path Forward	Ivan
3:00	Adjourn	

WGUEP Members

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

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

Other Participants

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

AGENDA

WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #5
Tuesday/Wednesday, 28 & 29 June 2011
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

<u>28 June 2011</u>

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome	Bill
8:15 – 8:30	Overview of Agenda	Ivan
8:30 – 9:00	WGUEP Products and Issue of Consistency with USGS Maps	Ivan
9:00 – 10:00	BRPEWG Workshop Issues	Mark/Tony
10:00 – 10:15	Break	
10:15 – 10:45	Update on Recurrence Models	Ivan
10:45 – 11:45	Update on Final Wasatch Central Segment Recurrence Rates and COVs	Chris
11:45 – 12:45	Lunch	
12:45 – 1:45	Inputs for Forecast and Moment Balancing	Patricia
1:45 – 2:15	Update on West Valley Fault Zone and Coseismic Rupture	Mike
2:15 – 2:45	Update on Other Faults	Bill
2:45 – 3:00	Break	
3:00 – 4:30	Path Forward on Use of Geodetic Data	Mark/Ivan
4:30 – 5:00	Wrap-up Discussion	All

<u>29 June 2011</u>

7:30 – 8:00	Continental Breakfast	
8:00 – 8:30	Update on Consensus Wasatch Front Earthquake Catalog	Walt/Jim
8:30 – 9:15	Spatial Smoothing Versus Uniform Source Zone(s)	Ivan
9:15 – 10:00	Mmax for Background Earthquakes	Ivan
10:00 – 10:15	Break	
10:15 – 12:00	Open Discussion	All
12:00 – 12:30	Lunch	
12:30 – 3:00	Open Discussion and Schedule	All
3:00	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

AGENDA

WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #6
Thursday/Friday, 17 & 18 November 2011
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

Thursday, 17 November

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome	Bill
8:15 – 8:30	Overview of Agenda	Ivan
8:30 – 9:15	Update on Consensus Wasatch Front Earthquake Catalog (Issue S4)	Walter/Jim
9:15 – 10:00	Recurrence Models (Issue S1)	Ivan
10:00 – 10:15	Break	
10:15 – 12:00	Overview of Methodology and Data Needs	Patricia
12:00 – 1:00	Lunch	
1:00 – 2:00	Update on Final Wasatch Central Segment Recurrence Rates and COVs	Chris
2:00 – 2:30	Update on Other Faults (Issue G3)	Bill
2:30 – 3:00	Path Forward on Use of Geodetic Data	Ivan
3:00 – 3:15	Break	
3:15 – 3:45	Spatial Smoothing (Issue S2)	Mark
3:45 – 4:30	Calculating M_{max} for Faults (Issue G1)	Susan/Chris
4:30 – 5:00	Modeling Antithetic Faults (Issue G2)	Mike

Friday, 18 November

7:30 – 8:00	Continental Breakfast	
8:00 – 8:30	Fault Dips (Issue G4)	Tony
8:30 – 9:00	M_{max} for Background Earthquakes	Ivan
9:00 – 9:30	Historical Versus Geologic Rates (Issue S3)	Ivan
9:30 – 10:00	Oquirrh-Great Salt Lake Fault	Susan
10:00 – 10:15	Break	
10:15 – 12:00	Open Discussion	All
12:00 – 1:00	Lunch	
1:00 – 3:00	Open Discussion and Schedule	All
3:00	Adjourn	

WGUEP Members

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

Other Participants
Steve Bowman, UGS

AGENDA

WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #7
Thursday/Friday, 16 & 17 February 2012
Utah Department of Natural Resources Building, Room 1040-1050 (1st floor)
1594 West North Temple, Salt Lake City

Thursday, 16 February

8:00 – 8:30	Continental Breakfast	
8:30 – 8:45	Overview of Agenda and Review of Last Meeting's To Do List	Ivan
8:45 – 9:30	Update on Consensus Wasatch Front Earthquake Catalog	Walter/Jim
9:30 – 10:00	Multi-Segment Ruptures on Normal Faults	David
10:00 – 10:15	Break	
10:15 – 11:15	Wasatch Central Segment Final RIs, Time-Dependent/Time Independent Weights, M_{max}	Chris/Nico
11:15 – 11:45	Wasatch End Segments Final Slip Rates and M_{max}	Mike/Chris
11:45 – 12:30	Lunch	
12:30 – 1:30	OGSL Parameters	Susan/Jim
1:30 – 2:15	Other Faults Final Parameters	Bill/Susan
2:15 – 2:45	Final Recurrence Models and Weights	Ivan
2:45 – 3:15	Final Seismogenic Thicknesses	Jim
3:15 – 3:30	Break	
3:30 – 4:15	Update on Geodetic Analysis	Jim/Mark/ David
4:15 – 5:00	Evaluation of Geodetic Models in NorCal	Ivan

Friday, 17 February

8:00 – 8:30	Continental Breakfast	
8:30 – 9:15	Background Seismicity Parameters	Mark/Ivan
9:15 – 10:00	Antithetic Fault Parameters	Mike
10:00 – 10:15	Break	
10:15 – 12:00	Preliminary Forecast	Patricia
12:00 – 1:00	Lunch	
1:00 – 2:00	Path Forward	All
2:00	Adjourn	

WGUEP Members

Ivan Wong, URS (Chair)
Bill Lund, UGS (Coordinator)
Walter Arabasz, UUSS
Mark Petersen, USGS
Steve Personius, USGS
David Schwartz, USGS
Chris DuRoss, UGS
Mike Hylland, UGS
Susan Olig, URS

Jim Pechmann, UUSS
Tony Crone, USGS
Nico Luco, USGS
Bob Smith, UUGG
Patricia Thomas, URS

Other Participants
Steve Bowman, UGS

AGENDA

WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #8
Wednesday/Thursday 8 & 9 August 2012
Utah Department of Natural Resources Building
1594 West North Temple, Salt Lake City

Wednesday, 8 August (Room 1040 – 1050)

10:30 – 10:45	Overview of Agenda and Review of Last Meeting's To Do List	Ivan
10:45 – 12:15	Final Wasatch Central Segment Parameters	Chris/Nico
12:15 – 1:00	Lunch	
1:00 – 2:00	Review Wasatch Fault Logic Tree	Patricia
2:00 – 2:30	Update on Consensus Wasatch Front Earthquake Catalog	Walter
2:30 – 3:00	Review OGSL Logic Tree	Patricia/Susan
3:00 – 3:15	Break	
3:15 – 4:00	Geodetic Modeling	Mark
4:00 – 5:00	Preliminary Results	Patricia

Thursday, 9 August (Room 2000)

8:00 – 8:30	Continental Breakfast	
8:30 – 10:00	Preliminary Results (continued)	Patricia
10:00 – 10:15	Break	
10:15 – 11:00	Preliminary Results (continued)	Patricia
11:00 – 12:30	To Do List/Final Report/Schedule	Ivan
12:30	Adjourn	

WGUEP Members

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

Other Participants

Steve Bowman, UGS

APPENDIX 3 – UTAH EARTHQUAKE WORKING GROUP MEETING SUMMARIES
Utah Quaternary Fault Parameters Working Group

SUMMARY
Utah Quaternary Fault Parameters Working Group Meeting
Tuesday, February 9, 2010
Utah Department of Natural Resources Building, Room 2000
1594 West North Temple, Salt Lake City

WELCOME AND INTRODUCTION

Bill Lund (Utah Geological Survey [UGS]) called the 2010 Utah Quaternary Fault Parameters Working Group (UQFPWG) meeting to order at 7:30 a.m. After welcoming Working Group members and guests (attachment 1), Bill summarized the UQFPWG's past activities and outlined the Working Group's purpose and goals for the future.

UQFPWG Purpose and Goals

- Helps set and coordinate the earthquake-hazard research agenda for the State of Utah.
- Reviews ongoing paleoseismic research in Utah, and updates the Utah consensus slip-rate and recurrence-interval database as necessary.
- Provides advice/insight regarding technical issues related to fault behavior in Utah and the Basin and Range Province.
- Identifies and prioritizes future Utah Quaternary fault studies.

TECHNICAL PRESENTATIONS

The following presentations were made on current paleoseismic research and related activities in Utah:

- Brigham City segment, trenching update; Tony Crone/Steve Personius, USGS
- Washington fault northern segment, trenching update; Bill Lund/Tyler Knudsen, UGS
- Washington fault Southern Beltway trenching investigation; Dave Simon, Simon - Bymaster, Inc.
- U.S. Bureau of Reclamation Utah fault studies update; Larry Anderson, USBR
- Bear River fault zone, trenching update; Suzanne Hecker, USGS
- Salt Lake City segment/West Valley fault zone investigation, progress report: Mike Hylland, UGS
- Working Group on Utah Earthquake Probabilities; Ivan Wong, URS Corp.

A scheduled presentation by Jim Evans, USU, on the East Cache fault zone trenching study was cancelled because Jim did not attend the meeting.

TECHNICAL DISCUSSION ITEMS

An Updated Chronology of Surface-Faulting Earthquakes on the Weber Segment, Wasatch Fault Zone; Chris DuRoss, UGS/Steve Personius, USGS

Recently updated and new paleoseismic data (UGS Miscellaneous Publication 05-8 [Nelson and others, 2006]; UGS Special Study 130 [DuRoss and others, 2009]) are now available for the Weber segment of the Wasatch fault zone (WFZ). Based on these newly available data and information from previously published paleoseismic studies on the segment, Chris DuRoss (UGS) and Steve Personius (USGS) prepared an updated chronology of surface-faulting earthquakes for the Weber segment. Their scope of work included: (1) carefully evaluating the paleoseismic data from the Kaysville (Swan and others, 1980; McCalpin and others, 1994), East Ogden (Nelson and others, 2006), Garner Canyon (Nelson and others, 2006), and Rice Creek (DuRoss and others, 2009) paleoseismic trench sites, (2) creating OxCal models for each site using stratigraphic information and reviewed ^{14}C and luminescence ages, (3) correlating the resulting individual earthquake-timing probability density functions (PDFs) from OxCal across the segment, (4) comparing and combining the site PDFs into a Weber segment chronology, and (5) estimating average recurrence intervals and slip rates based on the revised chronology.

Review of data for the Kaysville site revealed the possibility of a fourth earthquake between the two most recent earthquakes identified by McCalpin and others (1994). This earthquake would correlate with the second event identified at Rice Creek, Garner Canyon, and East Ogden. Evidence for the additional event includes soil unit S3 of McCalpin and others (1994) (similar to unit S2 of Swan and others, 1980) that predates the most recent earthquake, but apparently postdates faults and fissures formed in colluvium from the second earthquake (unit 4 of McCalpin and others, 1994). Unit S3 has a wedge shape, tapering from about 2 m thick near the fault scarp to about 0.5 m thick in a graben west of the scarp and appears to bury preexisting topography. Swan and others (1980) also show complex deformation below their soil unit S2 (S3) but few faults extending through it. However, it is possible that these faults and fissures extended up through the soil (unit S3) in the most recent event, but could not be accurately mapped. Chris and Steve plan to discuss this possible reinterpretation with the original study authors and restore the Swan and others (1980) trench map to look for additional evidence for the event.

A preliminary conclusion of the correlation analysis is that four earthquakes ruptured all paleoseismic sites on the Weber segment in the last about 4 ka (including the additional Kaysville event). The most recent earthquake, W1, occurred at 0.5 ± 0.15 ka (2 sigma), and older events (W2 to W4) occurred at 1.1 ± 0.7 ka, 3.1 ± 0.75 ka, and 4.1 ± 0.9 ka. A fifth earthquake, identified only at Rice Creek, occurred at 6.3 ± 1.2 ka. These earthquake times and uncertainties are similar to the UQFPWG consensus values (Lund, 2005), but have broader uncertainties:

UQFPWG (Lund, 2005)	New Chronology
• W1: 0.5 ± 0.3 ka (~2 σ)	0.5 ± 0.15 ka (2 σ)
• W2: 0.95 ± 0.45 ka	1.1 ± 0.7 ka
• W3: 3.0 ± 0.7 ka	3.1 ± 0.75 ka
• W4: 4.5 ± 0.7 ka	4.1 ± 0.9 ka
• W5: 6.1 ± 0.7 ka	6.3 ± 1.2 ka

Using the revised Weber segment earthquake chronology, the average recurrence interval (based on the four intervals between W5 and W1) is 1.5 ± 0.9 ky (0–3.2 ky at 2 sigma). The large uncertainty reflects short (~0.5–1-ky) intervals between W2–W1 and W4–W3 and longer (~2 ky) intervals between

W3–W2 and W5–W4, and is similar to estimates of Nelson and others (2006) and DuRoss and others, (2009). The preferred UQFPWG recurrence interval for the Weber segment is 1.4 ky (0.5–2.4 estimated two-sigma range).

The average interval slip rate is 2.0 mm/yr (0–4.6 mm/yr at 2 sigma), based on per-event displacement and revised individual-earthquake recurrence estimates. The large rate stems from moderate to large displacements and short recurrence times, but is similar to average post-mid-Holocene slip rate estimates of about 1 to 3 mm/yr reported in McCalpin and others (1994), Nelson and others (2006), and DuRoss and others, (2009). The preferred UQFPWG slip rate of the Weber segment is 1.2 mm/yr (0.6–4.3 estimated two-sigma range).

The UQFPWG members noted the general similarity between the UQFPWG consensus values and the new earthquake chronology and recurrence-interval estimates; however, the new mean slip-rate estimate is significantly higher than the UQFPWG consensus value. The UQFPWG decided to delay modifying their Weber segment consensus values until Chris and Steve speak with the authors of the original Kaysville studies (Swan and others, 1980; McCalpin and others, 1994) to resolve the question of three versus four surface faulting earthquakes at that site (south Weber segment) and adjust their earthquake chronology accordingly. The Working Group members also suggested that some reasonable minimum values of recurrence and slip rate be selected for the new recurrence-interval and slip-rate estimates to avoid reporting minimum recurrence-interval and slip-rate end values of zero (see above).

UQFPWG 2011 FAULT STUDY PRIORITIES

In 2005, the UQFPWG recommended that 20 Quaternary faults/fault segments in Utah be investigated to "adequately characterize Utah's earthquake hazard to a minimally acceptable level" (Lund, 2005). In 2007, the Working Group added five additional faults/fault segments to the priority list, and in 2009 they added a sixth fault segment (see table below). The UQFPWG reviews the progress made toward investigating the priority faults/fault sections annually (see above), and following that review identifies a list of highest priority faults/fault segments for additional study. The Working Group ranked the following five faults/fault segments as having the highest priority for study in 2011: (1) subsurface geometry of and connection between the East Bench and Warm Springs strands of the Salt Lake City segment WFZ, (2) penultimate event Provo segment WFZ, (3) long-term earthquake record on the Nephi segment WFZ, (4) Washington fault, and (5) chronology of mid- to late-Holocene surface-faulting earthquakes on the southern half of Weber segment WFZ. The following table shows the 2011 highest priority fault list and the current status for all priority faults/fault segments identified by the UQFPWG as requiring additional study.

UQFPWG 2011 highest priority list of Quaternary faults/fault segments requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level, and status of current paleoseismic investigations on all Utah priority faults/fault segments.

2011 Highest Priority Faults/Fault Sections For Study			
Fault/Fault Section	**Priority**	**Investigation Status**	**Investigating Institution**[1]
Warm Springs fault/East Bench fault subsurface geometry and connection	1	No activity	
Penultimate event Provo segment WFZ	2	Trench site reconnaissance	UGS
Long-term earthquake record Nephi segment WFZ	3	No activity	
Washington fault	4	Two trenching investigations	UGS/Simon-Bymaster
Mid- to late-Holocene earthquake chronology southern part Weber segment WFZ	5	No activity	
Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**[1]
Cedar City-Parowan monocline/Paragonah fault[2]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[2]	13	No activity	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault	2007	No activity	
Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution**[1]
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 UVU study ongoing	UGS/USGS/UVU
West Valley fault zone	2	Study funded for 2010	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Study funded 2009	UUGG
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley faults	14	Ongoing	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north end	2009	Study funded for 2010	UGS/USGS

[1]UGS (Utah Geological Survey), USGS (U.S. Geological Survey), UVU (Utah Valley University), UUGG (University of Utah Department of Geology & Geophysics), USU (Utah State University), USBR (U.S. Bureau of Reclamation).
[2]Used as an earthquake source on the USGS National Seismic Hazard Maps

ATTACHMENT 1

Meeting Attendees

Quaternary Fault Parameters Working Group

Tony Crone, USGS
Chris DuRoss, UGS
Kathy Haller, USGS
Ron Harris, BYU
Suzanne Hecker, USGS
Daniel Horns, UVU
Michael Hylland, UGS
William Lund, UGS
Susan Olig, URS Corp.
James Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
Larry Anderson, USBR
Ivan Wong, URS Corp.

Guests

Steve Bartlett, UUCE
Steve Bowman, UGS
Jessica Castleton, UGS
Ashley Elliot, UGS
Tyler Knudsen, UGS
Greg McDonald, UGS
David Simon, Simon-Bymaster, Inc.

ATTACHMENT 2
References Cited

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, 109 p., CD. [http://ugspub.nr.utah.gov/publications/bulletins/B-134.pdf]

DuRoss, C.B., Personius, S.F., Crone, A.J., McDonald, G.N., and Lidke, D.J., 2009, Paleoseismology of Utah Volume 18—Paleoseismic investigation of the northern Weber segment of the Wasatch fault zone at the Rice Creek trench site, North Ogden, Utah: Utah Geological Survey Special Study 130, 38 p., CD. [http://geology.utah.gov/online/ss/ss-130.pdf]

McCalpin, J.P., Forman, S.L., and Lowe, M., 1994, Reevaluation of Holocene faulting at the Kaysville site, Weber segment of the Wasatch fault zone, Utah: Tectonics, v. 13, no. 1, p. 1-16.

Nelson, A.R., Lowe, M., Personius, S., Bradley, L-A, Forman, S.L., Klauk, R., and Garr, J., 2006, Paleoseismology of Utah Volume 13—Holocene earthquake history of the northern Weber segment of the Wasatch fault zone, Utah: Utah Geological Survey Miscellaneous Publication 05-8, 39 p., CD. [http://ugspub.nr.utah.gov/publications/misc_pubs/MP-05-8.pdf]

Swan, F.H. III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

SUMMARY
Utah Quaternary Fault Parameters Working Group Meeting
Tuesday, February 15, 2011
Utah Department of Natural Resources Building, Room 2000
1594 West North Temple, Salt Lake City

WELCOME AND INTRODUCTION

Bill Lund (Utah Geological Survey [UGS]) called the 2011 Utah Quaternary Fault Parameters Working Group (UQFPWG) meeting to order at 8:00 a.m. After welcoming Working Group members and guests (attachment 1), Bill summarized the UQFPWG's past activities and outlined the Working Group's purpose and goals for the future.

UQFPWG Purpose and Goals

- Helps set and coordinate the earthquake-hazard research agenda for the State of Utah.
- Reviews ongoing paleoseismic research in Utah, and updates the Utah consensus slip-rate and recurrence-interval database as necessary.
- Provides advice/insight regarding technical issues related to fault behavior in Utah and the Basin and Range Province.
- Identifies and prioritizes future Utah Quaternary fault paleoseismic studies.

TECHNICAL PRESENTATIONS

The following presentations were made on current paleoseismic research and related activities in Utah:

- Preliminary results from the Penrose Drive trench on the Salt Lake City segment; Chris DuRoss, UGS
- Update on fault trenching at the Baileys Lake site, West Valley fault zone; Mike Hylland, UGS
- A brief summary of recent work on the northern Nephi segment of the Wasatch fault, Utah; Daniel Horns, Utah Valley University (UVU)
- Joes Valley fault zone; Lucy Piety, U.S. Bureau of Reclamation (USBR)
- Main Canyon and East Canyon faults; Lucy Piety, USBR
- Interactive Utah Quaternary fault map demonstration; Corey Unger and Mike Hylland, UGS

- HAZDOCS document archive presentation and progress report on UGS publishing USBR seismotectonic reports in the *Paleoseismology of Utah* series; Steve Bowman, UGS

- Utah Lake faults study – Preliminary progress report as of 2/15/2011; David Dinter, University of Utah Department of Geology and Geophysics (UUGG)

- Update on the Working Group on Utah Earthquake Probabilities; Ivan Wong, URS Corp.

- Integration of paleoseismic data from multiple sites to develop an objective earthquake chronology – Application to the Weber segment of the Wasatch fault zone, Utah; Chris DuRoss, UGS

- Implementation: The third dimension of seismic hazard mitigation; Ron Harris, Brigham Young University (BYU)

A scheduled presentation by Jim Evans, Utah State University, on the East Cache fault zone trenching study was cancelled because Jim failed to attend the meeting.

TECHNICAL DISCUSSION ITEM

- Recommendations to the U.S. Geological Survey (USGS) for the Quaternary Fault and Fold Database of the United States regarding the Joes Valley fault zone and the East Canyon and Main Canyon (East of East Canyon) faults; discussion moderator Bill Lund, UGS

Recent USBR investigations of the Joes Valley fault zone and the East Canyon and Main Canyon (East of East Canyon) faults (see http://geology.utah.gov/ghp/workgroups/uqfpwg.htm) completed as part of seismic hazard evaluations for the Joes Valley and East Canyon dams demonstrate that (a) the Joes Valley fault zone likely consists of shallow structures (a few to five kilometers deep) that may not be seismogenic, (b) clear evidence of Quaternary surface faulting is lacking on the East Canyon fault, and (c) the Main Canyon fault has had two surface-faulting earthquakes during the past 30,000 to 38,000 years, with the most recent earthquake likely occurring shortly before 5000 to 6000 years ago (Piety and others, 2010). The Joes Valley fault zone and East Canyon faults are currently classified as Class A faults in the Quaternary Fault and Fold Database of the United States. The Main Canyon (East of East Canyon) fault is classified as a Class B fault in the database. The definitions of Class A and B faults are as follows:

Class A — Geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed by mapping or inferred from liquefaction or other deformational features.

Class B — Geologic evidence demonstrates the existence of Quaternary deformation, but either (1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or (2) the currently available geologic evidence is too strong to confidently assign the feature to Class C, but not strong enough to assign it to Class A.

A Class C fault is defined as:

Class C Geologic evidence is insufficient to demonstrate (1) the existence of tectonic faulting, or (2) Quaternary slip or deformation associated with the feature.

The UQFPWG discussed the results of the USBR paleoseismic and geologic investigations for the Joes Valley fault zone and East Canyon and Main Canyon faults, and whether or not the working group should make a recommendation to the USGS to reclassify the Joes Valley fault zone and East Canyon fault as Class B faults and the Main Canyon fault as a Class A fault. Lucy Piety indicated that the USBR plans to continue studying the Joes Valley fault zone as funds and time permit (neither being presently available), because the USBR is not yet fully convinced that the fault zone is not seismogenic. Based on the USBR's continued interest in the Joes Valley fault zone, the UQFPWG decided to withhold making a recommendation regarding fault reclassification pending the results of future USBR investigations. However, it should be noted that in 2004, the UQFPWG recommended to the USGS that they (1) combine all of the various groupings of the Joes Valley fault system into a single fault group, and (2) reclassify the fault to the "S" ("suspected") category (attachment 2), which corresponds to the current Class B faults of the Quaternary Fault and Fold Database of the United States.

The UQFPWG concurred that the East Canyon and Main Canyon faults should be reclassified, and referred the new USBR information on those faults to Mike Hylland, UGS, for inclusion in the next UGS update of Utah Quaternary faults submitted to the USGS for revision of the Quaternary Fault and Fold Database of the United States.

UQFPWG 2012 FAULT STUDY PRIORITIES

In 2005, the UQFPWG recommended that 20 Quaternary faults/fault segments in Utah be investigated to "adequately characterize Utah's earthquake hazard to a minimally acceptable level" (Lund, 2005). Since then, the Working Group has added an additional 10 faults/fault segments to the list: five in 2007, one in 2009, one in 2010, and three in 2011 (see table 1 below).

The UQFPWG reviews the progress made toward investigating the priority faults/fault segments annually, and based on that review, establishes a short list of highest priority faults for future study. Following the 2011 review, the Working Group designated the following six faults/fault segments as the highest priority Utah faults for paleoseismic study in 2012: Brigham City segment WFZ rupture extent (north and south ends); long-term earthquake record Nephi segment WFZ; long-term earthquake record northern Provo segment WFZ; long-term earthquake record southern Weber segment WFZ; penultimate event Provo segment WFZ; and West Valley fault zone – Taylorsville fault. Additionally, the working group added the Hansel Valley fault to the list of "Other" priority faults. Table 2 shows the 2012 highest priority faults, and the current investigation status for all faults/fault segments identified by the UQFPWG as requiring additional study.

REFERENCES

Black, B.D., Giraud, R.E., and Mayes, B.H., 2000, Paleoseismic investigation of the Clarkston, Junction Hills, and Wellsville faults, West Cache fault zone, Cache County, Utah – Paleoseismology of Utah, Volume 9: Utah Geological Survey Special Study 98, 23 p., 1 plate. [http://ugspub.nr.utah.gov/publications/special_studies/SS-98.pdf]

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Geological Survey Bulletin 134, 109 p., CD. [http://ugspub.nr.utah.gov/publications/bulletins/B-134.pdf]

McCalpin, J.P., 1985, Quaternary fault history and earthquake potential of the Hansel Valley area, north-central Utah: Final Technical Report to the U.S. Geological Survey, Contract No. 14-08-001-21899, 37 p.

McCalpin, J.P., Robison, R.M., and Garr, J.D., 1992, Neotectonics of the Hansel Valley-Pocatello Valley corridor, northern Utah and southern Idaho, *in* Gori, P.L., and Hays, W. W., editor, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-G, 18 p.

Piety, L.A., Anderson, L.A., and Ostenaa, D.A., 2010, Late Quaternary faulting in East Canyon Valley, northern Utah - Paleoseismology of Utah, Volume 19: Utah Geological Survey Miscellaneous Publication 10-5, 45 p., CD. [http://geology.utah.gov/online/mp/mp10-05/mp10-05.pdf]

Robison, R.M., 1986, The surficial geology and neotectonics of Hansel Valley, Box Elder County, Utah: Logan, Utah State University, M.S. thesis, 120 p., scale 1:24,000.

Table 1. List of Quaternary faults/fault segments identified by the UQFPWG as requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level.

Fault/Fault Segment	**Original UQFPWG Priority (2005)**
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan segment WFZ	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	2007
Brigham City segment WFZ – most recent event	2007
Carrington fault (Great Salt Lake)	2007
Provo segment WFZ – penultimate event	2007
Rozelle section – East Great Salt Lake Fault	2007
Salt Lake City segment WFZ – northern part	2009
Warm Springs fault/East Bench fault subsurface geometry and connection	2010
Brigham City segment WFZ rupture extent (north and south ends)	2011
Long-term earthquake record northern Provo segment WFZ	2011
West Valley fault zone – Taylorsville fault	2011

Table 2. UQFPWG 2012 list of highest priority Quaternary faults/fault segments requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level, and status of current paleoseismic investigations on all currently identified Utah priority faults/fault segments.

2012 Highest Priority Faults/Fault Sections For Study

Fault/Fault Section[1]	Investigation Status	Investigating Institution[2]
Brigham City segment WFZ rupture extent (north and south ends)	No activity	
Long-term earthquake record Nephi segment WFZ	No activity	
Long-term earthquake record northern Provo segment WFZ	No activity	
Long-term earthquake record southern Weber segment WFZ	No activity	
Penultimate event Provo segment WFZ	Trench site reconnaissance	UGS
West Valley fault zone – Taylorsville fault	No activity	

Other Priority Faults/Fault Sections Requiring Further Study

Fault/Fault Section	Original UQFPWG Priority	Investigation Status	Investigating Institution[2]
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[3]	13	Black and others (2000)	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault[4]	2007	No activity	
Warm Springs fault/East Bench fault subsurface geometry and connection[4]	2010	No activity	
Hansel Valley fault[3]	2011	McCalpin, (1985), McCalpin and others (1992), Robinson (1986)	

Faults/Fault Sections Studies Complete or Ongoing

Fault/Fault Section	Original UQFPWG Priority	Investigation Status	Investigating Institution[2]
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 UVU study ongoing	UGS/USGS/UVU
West Valley fault zone	2	Study funded for 2010	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	Study funded 2009	UUGG
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley faults	14	Ongoing	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north end	2009	Study funded for 2010	UGS/USGS

[1]Listed in alphabetical, not priority order
[2]UGS (Utah Geological Survey), USU (Utah State University), USGS (U.S. Geological Survey), UVU (Utah Valley University), UUGG (University of Utah Department of Geology & Geophysics), USBR (U.S. Bureau of Reclamation)
[3]Earthquake source on the USGS National Seismic Hazard Maps
[4]Previous a highest priority fault/fault segment

ATTACHMENT 1

Meeting Attendees

Quaternary Fault Parameters Working Group

Tony Crone, USGS
Dave Dinter, UUGG
Chris DuRoss, UGS
Kathy Haller, USGS
Ron Harris, BYU
Daniel Horns, UVU
Michael Hylland, UGS
William Lund, UGS
Susan Olig, URS Corp.
James Pechmann, University of Utah Seismograph Stations
Steve Personius, USGS
Mark Petersen, USGS
Lucy Piety, USBR
Ivan Wong, URS Corp.

Guests

Dan Aubrey, Utah Division of Water Resources
Steve Bartlett, University of Utah Department of Civil Engineering
Doug Bausch, Federal Emergency Management Agency
Steve Bowman, UGS
Sarah Derouin, USBR
Rich Giraud, UGS
Greg McDonald, UGS
David Simon, Simon-Bymaster, Inc.
Anna Vargo, Natural Resources Conservation Service
Grant Willis, UGS

ATTACHMENT 2
Suggested UQFPWG revisions to the Joes Valley fault zone entry in the Quaternary Fault and Fold Database of the United States forwarded to the USGS in 2005.
Yellow highlights suggested text changes.

2453S, JOES VALLEY FAULT ZONE

Structure number: 2453S.
Comments: Previously treated as four separate fault zones: Hecker's (1993) fault numbers 13-5, 13-6, 13-7, and 13-8 (2454, 2453, 2455, and 2456, respectively, in Black and others [2003]).
Structure name: Joes Valley fault zone.
Comments: Includes the northern Joes Valley fault zone, consisting of the west, east, and intragraben faults, and the southern Joes Valley fault zone, consisting of the Muddy, Paradise, and intragraben faults.
Synopsis: Normal-fault-bounded graben, consisting of parallel, en echelon, and locally overlapping, north- to northeast-trending faults, which extend along the east side of the Wasatch Plateau (Foley and others, 1986). The northern Joes Valley fault zone is characterized by linear graben-bounding bedrock escarpments and fault scarps on Quaternary deposits. The southern Joes Valley fault zone has less stratigraphic throw and generally no scarps on Quaternary deposits. There is no net slip across the entire Joes Valley fault zone, and the seismogenic potential of the individual faults is poorly understood. The recurrence-interval estimates for the Joes Valley fault zone reflect the consensus values of the Utah Quaternary Fault Parameters Working Group (Lund, 2004). The preferred value of Lund (2004) approximates the "mean" based on available paleoseismic-trenching data, and the minimum and maximum values approximate two-sigma (5^{th} and 95^{th} percentile) confidence limits. The confidence limits incorporate both epistemic (e.g., data limitation) and aleatory (e.g., process variability) uncertainty (Lund, 2004).
Date of Compilation: 6/04.
Compiler and affiliation: Bill D. Black, Christopher B. DuRoss, and Greg N. McDonald (Utah Geological Survey), and Suzanne Hecker (U.S. Geological Survey).
State: Utah
County: Sanpete, Emery, and Sevier.
1° x 2° sheet: Price.
Province: Colorado Plateaus.
Reliability of location: Good.
Comments: Mapping from Foley and others (1986).
Geologic setting: Joes Valley is a long, straight, north-trending graben that splits the Wasatch Plateau, which is capped mainly by Tertiary Flagstaff Limestone. Faults forming the graben are subdivided into the northern and southern Joes Valley fault zones, based on the relative timing of fault movement. The northern Joes Valley graben is bounded by the east and west Joes Valley fault zones, which have the greatest amount of bedrock displacement near the center of the graben, with slip decreasing toward the north and south. Several intragraben faults on unconsolidated Quaternary alluvium exist, including the Middle Mountain fault and the Bald Mountain fault (Foley and others, 1986). The southern Joes Valley graben is bounded by the Muddy and Paradise faults, and several intragraben faults, which have very limited evidence for Quaternary movement.
Sense of movement: N.
Comments:
Dip: No data.
Comments:
Dip direction: E and W.

Geomorphic expression: Within the northern Joes Valley graben, the west fault is divided into the Huntington, Seely, and Dugway Hollow sections (from north to south, 4, 42, and 7.5 km long) based on relative age and displacement (Foley and others, 1986). Fault throw varies from less than 500 m across an eroded bedrock escarpment, partially buried by Pinedale (~11-14 ka) terminal moraines on the Huntington section, to ~150 m across the Dugway Hollow fault section, marked by a deeply incised scarp on colluvial veneer and bedrock. The Seely section has an undetermined amount of throw across two en echelon faults in Quaternary deposits. Scarps along the longer (en echelon) fault are 8-12 m high on latest Pleistocene (<30 ka) deposits, and 12-14 m high on latest Pinedale (11-14 ka) deposits along the shorter (en echelon) fault.

Foley and others (1986) divide the east fault (based on relative age and displacement) into the Miller Flat, Straight Canyon, and Ferron sections (from north to south, 8, 42,and 5 km long). Both the Miller Flat and Ferron sections have evidence for up to 100 m of total stratigraphic throw in bedrock. The Ferron section is expressed as a deeply incised scarp on colluvial veneer and bedrock, whereas a steep linear escarpment with up to 900 m of throw across bedrock and unconsolidated deposits marks the Straight Canyon section. Only the Straight Canyon section has significant inferred late Quaternary (<150 ka) displacement. The youngest measured displacement (2.5 m) is apparently due to monoclinal folding and may be the result of several small events.

Intragraben faults within the northern Joes Valley graben include the Bald Mountain faults, consisting of two horst-bounding scarps on upper Pleistocene deposits, and unfaulted Late Pleistocene moraines to the north and south. The Middle Mountain fault consists of several en-echelon, down-to-the-west scarps; the faults may be antithetic to the west Joes Valley fault based on similarities in movement histories. Trenches across the Middle Mountain fault expose two surface-faulting events separated by a soil inferred to be 14-30 ka in age; the events show measured displacements of <1 m for the most recent event and about 3 m for the earlier event.

The southern Joes Valley graben is bounded by the Muddy fault on the west and the Paradise fault on the east, with numerous smaller intragraben faults in between. Faults in the southern Joes Valley fault zone have less total stratigraphic throw, less topographic definition, and lower Quaternary activity rates than faults bounding the northern Joes Valley graben. Late Quaternary displacement on the faults is restricted to two short grabens. Gravels inferred to be more than 150 ka in age are displaced about 30 m in the grabens, but show no net tectonic displacement.

The estimated maximum credible earthquake for individual ruptures of faults within the Joes Valley fault zone (e.g., the west Joes Valley fault in the northern Joes Valley fault zone) is 7.5 (M_s). However the seismogenic nature of the faults is questionable, due to a lack of net slip across the entire graben and presently unidentified rupture pathways to the base of the seismogenic crust.

Age of faulted deposits: Holocene to Middle Pleistocene.

Paleoseismology studies: Fault trench studies are limited to the northern Joes Valley fault zone. Along the east Joes Valley fault a trench was excavated on the southeast side of Scad Valley, at the north end of the Straight Canyon section (site 2453S-1).
Stratigraphic and structural relations indicate at least four surface-faulting events since 150-300 ka, which is the interpreted age (based on amino acid racemization of snail shells) of the oldest unit exposed in the trench. The four events appear to have involved both brittle rupture and monoclinal folding. Two bulk-soil samples and one charcoal sample from the modern (unfaulted) soil profile yielded radiocarbon age estimates that place a minimum limiting age on the most recent event.

Several trenches excavated across the Middle Mountain fault (site 2453S-2), within the intragraben fault zone, exposed stratigraphic evidence for at least two surface-faulting events (Foley and others, 1986). The trenches were located east of the mouth of Reeder Canyon where two parallel en echelon scarps cross the three oldest of four upper Pleistocene alluvial fans (site 2453S-2). Radiocarbon age estimates from three bulk-soil samples of an unfaulted, organic-rich paleosol A horizon provide a minimum limiting age for the most recent event.

Foley and others (1986) excavated a trench on the Seely section of the west Joes Valley fault, about 270 m north of Littles Creek near the north end of a 450-m-long scarp crossing the highest of three alluvial terraces (site 2453S-3). Stratigraphic relations indicate a minimum of two surface-faulting events. Radiocarbon age estimates from a bulk-soil sample and charcoal derived from unfaulted colluvium provide a minimum age of the most recent event. Geomorphic relations and soils data provide additional broad constraints on earthquake timing.

An additional trench (site 2453S-4) across the inferred southern extension of the Middle Mountain fault (west-facing scarps on the west side of Joes Valley Reservoir) indicated multiple small (< 1 m) displacements (Foley and others, 1986).

Timing of most recent paleoevent: (2) Latest Quaternary (<15 ka).

Comments: Based on fault trench investigations and both radiocarbon dating and the relative ages of displaced deposits in the northern Joes Valley fault zone (Foley and others, 1986). The east Joes Valley fault experienced a minimum of four earthquakes in 250 ky, whereas the west Joes Valley and intragraben faults have each experienced a minimum of two earthquakes in the past ~30 ky. Individual earthquake timing is poorly constrained. Within the southern Joes Valley fault zone, the timing of the most recent paleoevent is estimated to be between the middle and late Quaternary (<750 ka).

Recurrence interval: 10 ky (preferred); minimum 5, maximum 50 ky (<30-300 ka)

Comments: Consensus recurrence-interval range reported in Lund (2004), based on a review of available fault-trench data for the northern Joes Valley fault zone by Foley and others (1986). The intentionally broad range reflects high uncertainty in the timing of events (Lund, 2004). Includes broadly constrained recurrence interval estimates for the Middle Mountain fault (10-15 ky) and west Joes Valley fault (10-20 ky) over a ~30 ky period of fault record, and the east Joes Valley fault (<60 ky) estimated over a ~250 ky period of record (Foley and others, 1986).

Slip rate: Unknown, probably <0.2 mm/yr.

Comments: Foley and others (1986) report no net slip across the Joes Valley graben, and question the seismogenic capability of the fault zone. Consequently, Lund (2004) did not estimate a slip rate range for the Joes Valley fault zone. Existing slip-rate estimates are limited to individual faults in the northern Joes Valley fault zone. Fault scarps at five localities along the Seely section of the west Joes Valley fault indicate about 12 m of displacement in deposits ranging in age from 11-30 ka, suggesting a long-term geologic slip rate of 0.4-1.1 mm/yr. The northern part of the section appears to have the largest Holocene displacement, where 12-14-m-high scarps are in Pinedale (11-14 ka) moraines. Geologic slip-rate estimates for the Middle Mountain fault (since ~30 ka) and east Joes Valley fault (since 150-300 ka) range from 0.1 to 0.3 mm/yr.

Length: End to end (km): 83
Cumulative trace (km): 350

Average strike (azimuth): N6°E

REFERENCES

Foley, L.L., Martin, R.A., Jr., and Sullivan, J.T., 1986, Seismotectonic study for Joes Valley, Scofield and Huntington North Dams, Emery County and Scofield Projects, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report No. 86-7, 132 p., scale 1:60,000 and 1:155,000.

Hecker, Suzanne, 1993, Quaternary tectonics of Utah with emphasis on earthquake-hazard characterization: Utah Geological Survey Bulletin 127, 2 plates, scale 1:500,000, 257 p.

Lund, W.R., 2004, Utah Quaternary Fault Parameters Working Group review of Utah paleoseismic-trenching data and determination of consensus recurrence-interval and vertical slip-rate estimates: Salt Lake City, Utah Geological Survey, unpublished Final Technical Report for the U.S. Geological Survey, National Earthquake Hazards Reduction Program, Contract No. 03HQGR0033, variously paginated.

SUMMARY
Utah Quaternary Fault Parameters Working Group Meeting
Tuesday, February 15, 2012
Utah Department of Natural Resources Building, Room 1040-1050
1594 West North Temple, Salt Lake City

WELCOME AND INTRODUCTION

Bill Lund (Utah Geological Survey [UGS]) called the 2012 Utah Quaternary Fault Parameters Working Group (UQFPWG) meeting to order at 8:00 a.m. After welcoming Working Group members and guests (attachment 1), Bill summarized the UQFPWG's past activities and outlined the Working Group's purpose and goals for the future.

UQFPWG Purpose and Goals

- Helps set and coordinate the earthquake-hazard research agenda for the State of Utah.
- Reviews ongoing paleoseismic research in Utah, and updates the Utah consensus slip-rate and recurrence-interval database as necessary.
- Provides advice/insight regarding technical issues related to fault behavior in Utah and the Basin and Range Province.
- Identifies and prioritizes future Utah Quaternary fault paleoseismic studies.

TECHNICAL PRESENTATIONS

The following presentations were made on current paleoseismic research and related activities in Utah:

- Paleoseismicity of the Salt Lake City segment—Results from the Penrose Drive trench investigation; Chris DuRoss, UGS
- Update on fault trenching at the Baileys Lake site, West Valley fault zone; Mike Hylland, UGS
- Searching for evidence of seismic events in lacustrine sediments in Utah Lake; Quincy Nickens, Brigham Young University
- Hurricane Cliffs hydropower and Lake Powell pipeline preliminary Quaternary fault investigation; Dean Ostenaa, Fugro, Inc.
- Blue Castle licensing project; Dean Ostenaa, Fugro, Inc.
- Summary of preliminary investigations of the Paunsaugunt fault, Utah; Bob Kirkham, RJH Consultants (no Power Point, hard copy handout)
- Utah Geological Survey Nephi segment trenching project, June 2012: Chris DuRoss, UGS

- Characterizing the central Wasatch fault zone for the Working Group on Utah Earthquake Probabilities; Chris DuRoss, UGS

- Comparison of moment rates from GPS observations and late Quaternary earthquakes on the Wasatch fault, Utah; Christine Puskas, UNAVCO
- The Working Group on Utah Earthquake Probabilities (WGUEP)—Background, goals, and progress; Ivan Wong, URS Corporation

- Basin and Range Province Earthquake Working Group II; Bill Lund, UGS

TECHNICAL DISCUSSION ITEMS

- East Cache fault zone study; discussion leader Bill Lund, UGS

A long-standing question exists regarding the status of the National Earthquake Hazard Reduction Program (NEHRP)-funded investigation titled *Earthquake Timing on the Southern Segment of the East Cache Fault Zone, Utah* by Utah State University (USU). Originally approved by NEHRP in 2007 as a one-year investigation, results of the study are not yet available to the public. Cache Valley is one of Utah's most populous regions off the Wasatch Front, and as such, the results of the USU investigation are important to seismic-hazard reduction for that area.

Dr. Jim Evans, USU Geology Department, is Principal Investigator for the study. Dr. Evans has been unable to attend past UQFPWG annual meetings to provide the UQFPWG with project updates, and did not attend this year's meeting as well. Dr. Suzanne Janecke, USU Geology Department, did attend this year's meeting, and stated that it was her understanding that Dr. Jim McCalpin, GEO-HAZ Consulting and project co-Principal Investigator, had assumed responsibility for completing the Final Technical Report, and that the report had been submitted to the U.S. Geological Survey (USGS). Tony Crone, USGS, checked the list of the Final Technical Reports submitted to the USGS External Grants Program office, and reported that the East Cache report was not among them. Bill Lund stated that he would contact Dr. McCalpin to determine the project's status.

Contact was subsequently made with Dr. McCalpin, who stated that the report is not yet finished. The graduate student who was working on the project for her MS thesis left USU without completing the project/degree, which resulted in incomplete data for the project. Dr. McCalpin indicated that he is aware that a Final Technical Report is over due to the USGS, and that he is attempting to pull together a report based on the limited available information. It is his hope that the report will be finished in the near future.

- Possible evidence for previously unrecognized Quaternary faulting in northern Utah, Dr. Suzanne Janecke, USU

Dr. Janecke asked the UQFPWG to explain the process for reporting newly discovered Quaternary faults, and how to get them included in the USGS *Quaternary Fault and Fold Database of the United States* (USGS, 2010). To demonstrate her point, Dr. Janecke made a brief Power Point presentation illustrating several areas in northern Utah (Weber Lake Bonneville delta front, near Hyrum Dam in Cache Valley, possible fault scarps in the bottom of Cache Valley, possible faults near the Legacy Highway in Salt Lake and Weber Counties) where, chiefly using remote sensing lineament analyses, she believes there is evidence for previously unrecognized Quaternary faulting.

The UQFPWG responded that evidence for newly identified Quaternary faults in Utah should be brought to the attention of Mike Hylland, UGS liaison with the USGS Quaternary Fault and Fold Database Program. The UGS makes periodic recommendations to the USGS regarding additional faults in Utah to include in the *Quaternary Fault and Fold Database of the United States* (USGS, 2010). However, before a fault can be added to the database, it must be conclusively demonstrated to be Quaternary active, and that evidence must be documented in a referenceable publication. Mike requested a copy of Dr. Janecke's Power Point presentation so he could review the evidence for Quaternary faulting in the areas she had identified.

UQFPWG 2012 FAULT STUDY PRIORITIES

In 2005, the UQFPWG recommended that 20 Quaternary faults/fault segments in Utah be investigated to "adequately characterize Utah's earthquake hazard to a minimally acceptable level" (Lund, 2005). Since then, the Working Group has added an additional 11 faults/fault segments to the list: five in 2007, one in 2009, one in 2010, and four in 2011 (see table 1 below). No new faults were added to the list in 2012.

The UQFPWG conducts an annual review of progress made toward investigating the faults/fault segments on their priority list. Based on that review, the Working Group establishes a short list of the highest priority faults/fault segments for future study. The list of highest priority faults/segments is published on the UGS web site, which h is then referenced by the USGS in their annual NEHRP request for proposals. Following the 2012 review, the Working Group created the following highest priority list: (1) Acquire new paleoseismic information in data gaps along the five central segments of the Wasatch fault zone (WFZ) – e.g., (a) Brigham City segment rupture extent (north and south ends), (b) long-tern earthquake record northern Provo segment, (c) long-term earthquake record southern Weber segment, (2) penultimate event Provo segment WFZ; and (3) West Valley fault zone – Taylorsville fault. Table 2 shows both the 2012 highest priority fault/fault segment recommendations, and the current investigation status for all faults/fault segments identified by the UQFPWG as requiring additional study.

Table 1. List of Quaternary faults/fault segments identified by the UQFPWG as requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level.

Fault/Fault Segment	Original UQFPWG Priority (2005)
Nephi segment WFZ	1
West Valley fault zone	2
Weber segment WFZ – most recent event	3
Weber segment WFZ – multiple events	4
Utah Lake faults and folds	5
Great Salt Lake fault zone	6
Collinston & Clarkston Mountain segments WFZ	7
Sevier/Toroweap fault	8
Washington fault	9
Cedar City-Parowan monocline/ Paragonah fault	10
Enoch graben	11
East Cache fault zone	12
Clarkston fault	13
Wasatch Range back-valley faults	14
Hurricane fault	15
Levan segment WFZ	16
Gunnison fault	17
Scipio Valley faults	18
Faults beneath Bear Lake	19
Eastern Bear Lake fault	20
Bear River fault zone	2007
Brigham City segment WFZ – most recent event	2007
Carrington fault (Great Salt Lake)	2007
Provo segment WFZ – penultimate event	2007
Rozelle section – East Great Salt Lake Fault	2007
Salt Lake City segment WFZ – northern part	2009
Warm Springs fault/East Bench fault subsurface geometry and connection	2010
Brigham City segment WFZ rupture extent (north and south ends)	2011
Long-term earthquake record northern Provo segment WFZ	2011
West Valley fault zone – Taylorsville fault	2011
Handel Valley fault	2011

REFERENCES

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, 109 p., CD, online <http://ugspub.nr.utah.gov/publications/bulletins/B-134.pdf>.

U.S. Geological Survey, 2010, Quaternary fault and fold database of the United States: Online, <http://earthquake.usgs.gov/regional/qfaults/>.

Table 2. UQFPWG 2013 list of highest priority Quaternary faults/fault segments requiring additional study to adequately characterize Utah's earthquake hazard to a minimally acceptable level, and status of current paleoseismic investigations for all currently identified Utah priority faults/fault segments.

2012 Highest Priority Faults/Fault Sections For Study		
Fault/Fault Section[1]	**Investigation Status**	**Investigating Institution[2]**
Acquire new paleoseismic information in data gaps along the five central segments of the WFZ – e.g., (a) Brigham City segment rupture extent (north and south ends); (b) long-tern earthquake record northern Provo segment; (c) long-term earthquake record southern Weber segment.	No activity	
Penultimate event Provo segment WFZ	No activity	
West Valley fault zone – Taylorsville fault	No activity	

Other Priority Faults/Fault Sections Requiring Further Study			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Cedar City-Parowan monocline/Paragonah fault[3]	10	No activity	
Enoch graben	11	No activity	
Clarkston fault[3]	13	Black and others (2000)	
Gunnison fault	17	No activity	
Scipio Valley faults	18	No activity	
Faults beneath Bear Lake	19	No activity	
Eastern Bear Lake fault	20	No activity	
Carrington fault (Great Salt Lake)	2007	No activity	
Rozelle section, Great Salt Lake fault[4]	2007	No activity	
Warm Springs fault/East Bench fault subsurface geometry and connection[4]	2010	No activity	
Hansel Valley fault[3]	2011	McCalpin, (1985), McCalpin and others (1992), Robinson (1986)	

Faults/Fault Sections Studies Complete or Ongoing			
Fault/Fault Section	**Original UQFPWG Priority**	**Investigation Status**	**Investigating Institution[2]**
Nephi segment WFZ	1	UGS Special Study 124 USGS Map 2966 New UGS study funded 2012	UGS/USGS
Long-term earthquake record Nephi segment WFZ	1a	Funded for 2012	UGS/USGS
West Valley fault zone (Granger fault)	2	Ongoing	UGS/USGS
Weber segment WFZ – most recent event	3	UGS Special Study 130	UGS/USGS
Weber segment WFZ – multiple events	4	UGS Special Study 130	UGS/USGS
Utah Lake faults and folds	5	On going	UUGG
Great Salt Lake fault zone	6	Ongoing	UUGG
Collinston & Clarkston Mountain segments WFZ	7	UGS Special Study 121	UGS
Sevier/Toroweap fault	8	UGS Special Study 122	UGS
East Cache fault zone	12	Ongoing	USU
Wasatch Range back-valley fault (Main Canyon fault)	14	UGS Miscellaneous Publication 10-5	USBR
Hurricane fault	15	UGS Special Study 119	UGS
Levan segment WFZ	16	UGS Map 229	UGS
Brigham City segment WFZ – most recent event	2007	Ongoing	UGS/USGS
Bear River fault zone	2007	Ongoing	USGS
Salt Lake City segment WFZ – north end	2009	On going	UGS/USGS

[1]Not in priority order
[2]UGS (Utah Geological Survey), USU (Utah State University), USGS (U.S. Geological Survey), UUGG (University of Utah Department of Geology & Geophysics), USBR (U.S. Bureau of Reclamation)
[3]Earthquake source on the USGS National Seismic Hazard Maps
[4]Previous highest priority fault/fault segment

ATTACHMENT 1

Meeting Attendees

Quaternary Fault Parameters Working Group

Tony Crone, USGS
Chris DuRoss, UGS*
Kathy Haller, USGS
Ron Harris, BYU
Daniel Horns, UVU
Michael Hylland, UGS*
William Lund, UGS*
Susan Olig, URS Corp.
James Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
Lucy Piety, USBR
Bob Smith, UUGG
Ivan Wong, URS Corp.*

Guests

Bob Biek, UGS
Steve Bowman, UGS
Jessica Castleton, UGS
Rich Giraud, UGS
Amanda Hintz, UGS
Adam Hiscock, UGS
Greg McDonald, UGS
Quincy Nickens, BYU*
Dean Ostenaa, Fugro, Inc.*
Christine Puskas, UNAVCO*
David Simon, Simon-Bymaster, Inc.
Nathan Toke, UVU
Anna Vargo, NRCS
Grant Willis, UGS

*Speaker

RESULTS OF THE FEBRUARY 8, 2010
UTAH GROUND-SHAKING WORKING GROUP MEETING

Members:	Guests:
Ivan Wong	Steve Bowman
Mark Petersen	Michael Thorne
Bill Stephenson	Jamie Farrell
Walter Arabasz	Chris DuRoss
Greg McDonald	Morgan Moschetti
Harold Magistrale	Jacobo Beilak
Kris Pankow	Ralph Archuleta
Jim Pechmann	Mike Hylland
Relu Berlacu	Christine Puskas
Kim Olsen	Anthony Crone
Daniel Roten	Bob Carey
Robert Smith	Ashley Elliott
	Charles Williamson

MEETING SUMMARY

The meeting was convened at 7:30 by Ivan Wong. Introductions of the attending members and guests were performed. Wong gave a brief overview of the purpose of the meeting, summarized the original objectives of the working group and reviewed last year's priorities. The following technical presentations were made:

Ivan Wong – Analysis of ANSS Data for Stress Drop and Kappa

The study evaluated critical factors controlling ground-shaking hazard along the Wasatch Front: stress drop, kappa, and crustal attenuation (Q[f]) using ANSS data.
Previous studies have suggested earthquake ground motions in extensional regimes may be lower than in California for the same magnitude and distance. The difference may be from lower stress drops of extensional versus compressional earthquakes (McGarr, 1984).

For earthquake hazard studies of the Wasatch Front:

- No systematic evaluation of earthquake stress drop has been performed;
- No studies have been performed to evaluate kappa; and
- Limited studies have been performed to estimate Q(f) (Brockman and Bollinger, 1992; Jeon and Herrmann, 2004)

The study analyzed available strong-motion and broadband data from ANSS stations in the central Wasatch Front region using a non-linear, least squares inversion of Fourier amplitude spectra (iterative process for best fit scheme developed by Silva)

- Analyzed ANSS data includes 17 events recorded between May 2001 and November 2007; M 3.0 to 4.2; 18 to 62 stations recording.
- Preliminary results indicate low stress drops of less than 25 bars, a Qo and eta of 103 and 0.69, respectively, and kappa values for soil and rock of 0.03 and 0.04 sec, respectively.

- Some of the inversions show poor comparisons between modeled results and observed spectra suggesting some of the seismic stations may have strong site effects. Further evaluation is to be performed.

Jim Pechmann – Sonic Log Analyses for the Wasatch Front CVM

The study evaluated sonic logs to compare with the Hill et al. (1990) model that used 2 sonic logs, 3 density logs, and one seismic reflection profile, all in the northern part of SLV.
This study looked at 24 sonic logs, 17 in Quaternary deposits, 7 in bedrock (3 outside the CVM area); depths ranging from 0.9 to 5.3 km (median ~2 km).
The study determined average Vp profiles above R1, between R1 and R2, and in bedrock for use in the CVM.

Conclusions:
- The sonic logs are generally consistent with Hill et al. basin model.
- Results confirm that the largest velocity contrast is at R2.
- Vp below R2 is typically ~1 km/s lower than the Hill et al. model.
- Mean bedrock Vp increases from ~3.0 km/s near surface to ~5.8 km/s at 5 km depth.
- Lateral variabilities of Vp in bedrock are comparable to that in basins.

Harold Magistrale – Update on Modifications to the WFCVM

WFCVM update (version 3c)
- Surface to R1: Vp from piecewise linear fits to geometric mean from sonic-log analysis or from modified mudline if Vs is from geotechnical data.
- **R1 to R2: Vp from piecewise linear fits to geometric mean from sonic-log analysis or from Poisson's ratio if Vs is from geotech data.**
- R2 to R3: Basement now at R3; Vp from Faust's relation
- Basement: Vp from sonic logs 0 to 4 km, from tomography below 5 km, and a weighted average of the two from 4 to 5 km; Vp/Vs gradient from 2.0 to 1.74 from 0 to 1 km; corrected bug "47,000 feet" to 47,000 meter"
- Compared simulated ground motions from versions 2e and 3c with actual ground motion recordings; some showed improved fit.

Greg McDonald – WFCVM discussion

- **The latest version (v3c) supersedes previous versions; no value in making earlier versions available.**
- UGS will host web site having CVM and associated data downloadable.
- A "readme" file will be available with CVM bundle detailing updates to current version.
- No immediate plans for CVM update. Other factors (e.g., Q, kappa) are likely more important for refining ground motion models.
- Salt Lake Valley portion of the CVM is fairly good; other Wasatch Front basins/backvalleys need refinement; there is not much existing data and what there is has already been incorporated into the CVM; the gravity data used in the regional model (Mabey) needs to be reviewed, possibly reprocessed.

Presentation/Discussion of Different Wasatch Front Ground Motion Models

Morgan Moschetti – USGS Plans for Analysis of the CVM

Current USGS efforts in calculating Wasatch Front ground motions include:

- Modeling ground motions for the current CVM (version 3c).
- Evaluation of the CVM for improvements to the regional Vs model.
- Linear, kinematic modeling with Hercules finite-element code developed by Carnegie Mellon University.
- Validation runs using Lehi and Magna events up to 0.5 Hz on desktop computers

Future modeling efforts include:

- Perform validation runs on USGS or Teragrid clusters for Lehi and Magna events to ~2 Hz.
- Develop scenario earthquake on Salt Lake segment of the Wasatch fault for comparison with other groups models.
- Evaluate effects of slip history and fault geometry on ground motions.

Modifying regional Vs model:

- Presently there is no regional-scale crustal Vs model for the region.

Dispersion maps from ambient seismic noise

- Ambient noise tomography; maps in 6-40 s period band
- Develop earthquake surface wave tomography maps to 100 s
- Combine inversion for Vs structure – regional model
- Current resolution ~50 km with improvements from incorporating local data. Combine existing USArray data with shorter inter-station pair measurements in the Wasatch Front region.
- Invert dispersion maps for 3-D Vs structure; maps from ambient seismic noise can incorporate some stratigraphic velocity structure and reduce velocity trade offs.

Jacobo Bielak – 3D Nonlinear Earthquake Ground Motion Simulation in the Salt Lake Basin Using the Wasatch Front CVM

Objectives of Future Work:

- Examine how earthquake ground motions along Wasatch Front are affected by nonlinear soil behavior in conjunction with other factors (e.g., depth, edge effects, focusing) using Hercules; limited to low frequencies (<1.5-2 Hz)
- Assess the impacts on ground motions as soil becomes progressively nonlinear - under what conditions and to what extent - using elastoplatic constitutive laws
- Incorporate geostatic stresses and extend model to more realistic constitutive relations.
- Evaluate sites in Salt Lake Valley in generalized silt/clay and sand/gravel geologic settings
- The Volvi EuroSeisTest verification exercise is useful as an example; compared elastic and elastoplastic response to horizontal displacement for sites in elongate, basin setting comparable to Wasatch Front basins.

Ralph Archuleta – Ground Motions in Salt Lake Basin from Dynamic Modeling of a M7 Earthquake on the Wasatch Fault

Modeled earthquake on the Salt Lake segment; simple, linear trace,150 deg strike, 50 deg dip (west),. 30 km trace x 18 km downdip, 50 m grid
Six stations used for ground motion results
Vs ranged from 85 to 3661 m/s
Dynamic finite-element model incorporates slip-weakening friction law
Basic parameters include:

- minimum Vs - 500 m/s
- maximum frequency - 1 Hz.
- initial normal stress - 36 MPa
- $\mu0$ – 0.55; μd – 0.448; μs – 0.66; S – 1.1
- stress drop - 30 bars over 0.25 m
- tmax – 30 s
- hypocentral depth - 11.5 km

Summary:

- There is a strong concentration of energy near the crack tip with peak horizontal velocities >3m/s
- Hanging wall, sediments have strongest effect on ground motions
- Basin effects lead to longer duration ground shaking with amplitudes ~0.2-0.5 m/s far from the fault

Kim Olsen/Daniel Roten – 3D Nonlinear Broadband Ground Motion Predictions for M7 Earthquakes on the Salt Lake City Segment of the Wasatch Fault using Dynamic Source Models

Re-validation of CVM: some improvement in wavefit at some stations (notably Northern SL basin) but in general, little to no improvement was observed.

M7 scenario earthquakes:

- Four rupture models obtained from simulation of spontaneous rupture on a planar, vertical fault with depth-dependent normal stress for a 50-degree dip
- Planar rupture models were projected onto 3-D model of Wasatch fault that incorporates tear fault connecting East Bench to Warm Springs section
- Modeled six scenario earthquakes with different hypocenters for frequencies up to 1 Hz, using a minimum shear-velocity of 200 m/s.
- Produced average maps of 2s-SAs (spectral accelerations) and 1s-SAs, compared to next-generation attenuation models (NGA) and results of Solomon et al. (2004)
- Generated broadband (0-10 Hz) synthetics on a 200m grid for each rupture model
- Performed fully-nonlinear 1-D simulations along three profiles across the Salt Lake basin.
- Reference strain needed for these nonlinear simulations was derived from plasticity index using empirical relationship modified for Bonneville clays (Bay and Sasanakul, 2005); plasticity index was assigned to each site using Quaternary site response units
- Comparisons of broadband and nonlinear peak ground acceleration and 5 Hz spectral accelerations to NGA predictions

Conclusions:

- Ground motion tends to be larger on low-velocity sediments on the hanging wall side of the fault than on outcropping rock on the footwall side
- High low-frequency ground motions near fault stepovers (Holladay, East bench-Warm Springs) for some scenarios, which are due to a Love wave in the case of the Holladay stepover
- Strong along-strike and along-dip directivity effects
- Compared to Solomon et al. (2004), simulations predict larger ground motion on the hanging wall side, but lower values on the footwall side
- Simulated 2s-SAs agree well with NGA predictions, while simulated 1s-SAs exceed NGA by up to 75%. Maximum SAs are reached at ~2km from fault trace.
- PGAs derived from broadband synthetic seismograms are exceeding those predicted by NGA models by more than one standard deviation at near-fault locations on the hanging wall side
- Synthetic ground motions obtained from fully nonlinear 1-D simulations exhibit PGAs and SAs that are generally consistent with NGA models, even when taking into account the uncertainty in the nonlinear soil parameters

Ivan Wong – Modeling Near-Surface Effects

Discussed formation of a sub-working group to evaluate site-amplification factors pending results of study of non-linear effects (Beilak)
Objectives:

- Determine a suite of amplification factors to model site response effects for urban hazard maps using both geotechnical and empirical approaches
- Need to involve geotechnical engineering community (e.g., Bartlett, Bay)

Mark Petersen – USGS Perspective; Comparison of Models/Differences; Applicability for Urban Hazard Maps, Direction of Modeling; Priorities for Future Research

Ultimate goal is to make urban hazard maps that are meaningful for all users (e.g., city planners, developers)
Important to stress UGSWG is behind and supports hazard maps
Optimal products:

- Based on 3-D simulations and empirical ground motion models
- Broadband 10-0.1 Hz (0.1-10 s)
- Probabilistic and scenario (**M** 7) maps of Salt Lake County urban hazard

Initially focus on Salt Lake segment of Wasatch fault; later incorporate other faults (e.g., Great Salt Lake faults)

Need to coordinate and facilitate interaction between modeling groups; perhaps via internet connection; physically meet yearly.
Need a test case to compare different models; linear as baseline then nonlinear; some models have been vetted/validated to some extent

Test model for validation/verification; short and long periods

- Prescribe Lehi or Magna event (verification)
- Use WFCVM v3c
- Prescribe damping model, slip history, and frequency (0.1-1 Hz)

- Prescribe mesh resolution (output grid spacing and format) and minimum Vs

General methodology
- Finite-fault geometry (Salt Lake segment used in Roten et al. model)
- Allow for variable slip functions (supershear, etc)

Groups need database of 17 largest events **M** 2-4 compiled by URS/Wong
Submit group proposal (long-period modelers) for funding through co-op agreement
Need to establish time when groups will be ready to meet and compare results (possibly March 2011)
Make progress toward dynamic modeling on complex (segmented) fault
Discuss high-frequency stochastic methods
Phase 3 – use results to estimate ground motions from other faults, add uncertainty from phases 1 and 2, calculate hazard for urban hazard maps

The meeting adjourned at 12:00 pm.

SUMMARY OF THE FEBRUARY 14, 2011
UTAH GROUND SHAKING WORKING GROUP MEETING

Attendees:

Ivan Wong	Morgan Moschetti	Doug Bausch
Steve Bowman	Qiming Liu	Chris DuRoss
Greg McDonald	Jacobo Bielak	Keith Koper
Mark Petersen	Ralph Archuleta	Bob Smith
Harold Magistrale	Christine Puskas	Kim Olsen
Anthony Crone	Jim Pechmann	Kris Pankow
Ricardo Taborda	Bob Carey	

The meeting convened at 8:00 am with introductions. Ivan Wong (Working Group Coordinator) gave a brief overview of the working group history, objectives, and accomplishments, and summarized last year's priorities and this year's objectives:

- Presently have a good seismic source model for maps.
- Need better basin effect parameters (kappa, Q[f]).
- Ultimate goal is to produce urban hazard maps (UHMs) for the Wasatch Front urban corridor; initially for the Salt Lake basin, expand to Weber-Davis Counties, Utah Valley, etc.
- Roughly two-year time frame to produce UHMs; may need to establish a more stringent time frame.
- The working group needs to consider what remains to be done to produce the initial maps, and what should be considered for the upcoming U.S. Geological Survey (USGS) National Earthquake Hazard Reduction Program (NEHRP) Request for Proposals (RFP) cycle.

Technical Presentations

Ricardo Taborda/Jacobo Bielak - 3D Nonlinear Earthquake Ground Motion Simulation in the Salt Lake Basin Using the Wasatch Front Community Velocity Model

Model domain – Extent from the Wasatch Front Community Velocity Model (WFCVM) (originally from Solomon and others, 2004); 60 km depth
Modeled 3 source types:

- Point: M_W 6.0 centered at Salt Lake City
- Line: M_W 6.3 Bearing 153^o
- Plane: (from Archuleta) M_W 6.8; Strike 153^o; Dip 50^o SW

Modeled using Hercules simulation (developed at Carnegie Mellon University [CMU]) - Vs<500 m/s treated as nonlinear
(to date, point and line source models have been run)

Linear: Plane source; $V_s$min-100 m/s; fmax-1.0 Hz
Linear and Non-linear: Point and line source; $V_s$min-500 m/s; fmax-0.5 Hz
Rate-dependent plasticity (Hookes's law)

Initial results:

- Acceleration of 20 m/s^2 and greater observed.
- Point source appears to provide too much focused input.
- Linear vs non-linear - some de-amplification observed in deeper parts of the basin.
- Synthetic time histories - very low accelerations observed for non-linear.

- Forcing non-linear at low accelerations to get material properties for scaling up for larger events/verify methodology.
- Significant non-linear behavior observed near fault.

To complete this phase of the project:

- Need to scale down the model domain; restrict to Salt Lake basin to improve resolution/computing times.
- Need alternative source models.
- Need to perform several runs to adjust soil parameters.

This phase of the project is anticipated to be completed by fall 2011. Future work may include modeling dynamic rupture on a 3D fault.

Ivan Wong/Jim Pechmann - Analyses of Earthquake Source, Path, and Site Parameters From ANSS Data Along the Wasatch Front, Utah

The project was established to evaluate critical factors controlling earthquake ground-shaking hazard along the Wasatch Front. The Next Generation Attenuation (NGA) database has limited data for normal faults (most are from Italy). Thus, analysis of strong motion and broadband data from central Wasatch Front Advanced National Seismic System (ANSS) stations using an inversion scheme developed by Walt Silva was employed: non-linear, least-squares inversion of Fourier amplitude spectra using rock amplification factors to get average set of factors at soil sites.

Seventeen events were used in the analysis:

- M 3.0 to 4.2.
- Earthquakes between May 2001 and November 2007.
- Eighteen to 68 stations recording.

Results:

- Some synthetic seismograms showing better fit with new data; others not.
- Stress drop consistent with other studies; stress drops lower in extensional regimes for earthquakes of the same magnitude.
- Report has been submitted to USGS NEHRP; some additional work is needed before the project is finalized.

Kris Pankow - Characterization of Shallow S-Wave Velocity Structures in Southwestern Utah

Objective:
To obtain better geologic site conditions data for Shakemaps in southern Utah. Current maps use data that are extrapolated from Wasatch Front site conditions using basic geologic relations. Presently, there are 10 strong motion instruments deployed in southern Utah.
Multi-mode spatial autocorrelation (SPAC) methodology arrays were employed (4-station equilateral triangle) at sites with favorable logistics. A total of six sites were selected on various Quaternary and bedrock units.

Results:
Comparisons of V_s profiles from this study (SPAC) to ellipticity models vary, but in general show reasonable results.
All sites fall under NEHRP site class C - Strong ground motion amplification is unlikely.

Ralph Archuleta - Ground Motions in the Salt Lake Basin from Dynamic Modeling of a M7 Earthquake on the Wasatch Fault

The project involves modeling of ground motions using a finite element, meshed dynamic model. The modeling domain is restricted to the Salt Lake Valley area based around a single plane source representing a simplified version of the Salt Lake City segment (strike 153^{o}; dip 50^{o} SW). Shear-wave velocities (V_s) were truncated at 500 m/s. Four new NGA relations were used for comparison. The model included a velocity strengthening zone - selected a 2 km depth; typically between 1-3 km depths are used, but they can possibly be down to 4 km. The effect is a slowing of acceleration towards surface that mutes the seismic signature.

Initial modeling results show greatest ground motion affects about 5 km from the fault on the hanging wall. Results suggest that currently the NGA is overestimating ground motions especially on the hanging wall. Additionally, fault partitioning/Coulomb stress transfer has a significant effect on ground shaking/rupture propagation.

Sensitivity testing of different parameters (source locations, geometries, overlap scenarios, etc.) is still needed. Preliminary results suggest a multiple-segmented fault would generate less damaging ground motions than for the same magnitude event.

Further model testing required: will use established baseline, then vary segments.
Eventually need a better fault model from geologists for testing; deep, low-angle loaded fault that transfers slip to the surface.

Kim Olsen - Approximate Linear-to-Nonlinear Correction Factors for Broadband Synthetics Computed for the Salt Lake Valley

Brief summary of last year's work: Generated spontaneous rupture simulations using WFCVM to produce planar rupture model and map on irregular surface approximating fault geometry. Modeling incorporated low-frequency finite-difference synthetic seismograms with high-frequency scattering operators.

The fault trace used for modeling was a representation of the Salt Lake City segment that included a tear fault connecting the East Bench and Warm Springs faults; extrapolated the surface trace at depth. Incorporated a 2-4 km deep velocity strengthening zone.
Tested 6 hypocenters: location has large effect on ground shaking; hypocenters usually near non-conservative barrier; preferred 20 km depth, tested one at shallower, 10 km depth.

- Results confirm findings from prior studies that larger ground motions occur on low-velocity sediments on the hanging wall rather than on rock on the footwall.
- Results show strong fault directivity basin effects both along-strike and along-dip.
- Linear results incorporate empirical relations/non-linear soil parameters from laboratory testing of Lake Bonneville fine-grained deposits by Jim Bay, USU.
- Non-linearity at higher frequencies may amplify ground motions (not modeled).
- Correction factors for broadband spectral accelerations can be derived from profiles.
- Applying non-linearity correction factors reduces spectral acceleration (SA), especially in the northeast part of Salt Lake Valley.

Broadband synthetic seismograms – Low-frequency finite-difference synthetic seismograms are combined with high-frequency scattering operators into broadband seismograms using an amplitude and phase matching algorithm.

- Results suggest highest 2s SAs occur about 2-3 km from fault on hanging wall.

- 2s and 1s SAs are generally in agreement with NGA model predictions.
- 0.2s SAs derived from broadband synthetic seismograms greater than NGA models by over 1 sigma near the fault trace on the hanging wall, but improve with distance from the fault. 1.0s SAs lower than those of Solomon and others (2004) on the footwall.
- Non-linear site response controls higher-frequency ground motions.

The project is essentially completed; results will soon be published and made available to working group via the UGS website.

Morgan Moschetti - Long period (T>1s) Earthquake Simulations for Evaluation of the WFCVM

The objective of the study is to compare observed and synthetic seismograms using the WFCVM to identify and characterize any misfits and biases in preparation for modeling with kinematic source models. The project is also testing ground-motion model sensitivity to the effects of various parameters by introducing simple perturbations. The work involves comparison of WFCVM with ambient noise tomography (ANT) regional V_s model developed for the western United States.
Three events were used for comparisons:
- Randolph M 4.5
- Tremonton M 3.7
- Ephraim M 3.8

The Hercules model developed at CMU was used for testing. Simulations were run to 0.5 Hz (regional model, geotechnical layer) and to 1.0 Hz (R1 and R3 perturbations).
The observed Raleigh wave velocities from the WFCVM were generally faster, but within 10 percent of observed records.

To test WFCVM layer above R1, kriging (weighted spatial averaging) of borehole data above R1 supplemented with CVM-generated profiles using MATLAB was performed. The results showed a 15 percent decrease in mean response spectra ratio and 6 percent increase in mean peak ground velocity (PGV) ratio. Comparison of PGV from WFCVM and the regional ANT model were variable: For the Ephraim event, WFCVM was a 40 percent improvement, for Randolph, ANT decreased 11 percent, and for Tremonton, WFCVM was an 8 percent improvement. WFCVM-generated V_s values were compared to topography-derived values from Wald and Allen (2007) (geotechnical layer [GTL]) (Wald and Allen concluded their method does not work well along the Wasatch Front likely due to Lake Bonneville-related topography/lithology). Observed a several percent improvement in mean response spectra ratios. Comparison of PGVs showed minor changes. Tested model with perturbations to R3 volume; to date, have tested 1 Hz simulation for Randolph event.

Continued work:
- Sensitivity testing for 1 Hz – duration, PGV, peak ground acceleration (PGA), spectral acceleration (SA).
- Perform additional parameter tests.
- Perform kinematic ground motion modeling for the Salt Lake Valley.

USGS Wasatch Front Urban Hazard Maps Discussion

The Ground Shaking Working Group is at the point now where urban hazard maps need to be produced and released to the user community.
Objective is to produce 3D model in urban areas and ultimately PGA maps.

How product is presented to users is important (maps; Web-based; interactive; location coordinate input/output)

General considerations:

- Need time history maps to 10s; at least 0.2s SAs needed for building codes.
- Need systematic examination of uncertainties: can get at epistemic uncertainties from different modeling groups; aleatory uncertainties inherently more difficult.
- Initial maps will be produced for Salt Lake Valley; eventually expand to other areas along the Wasatch Front.
- Urban hazard maps need ground motion data/response spectra at each grid point.
- Need to combine long- and short-period data (e.g. Olsen and Roten) – nonlinear broadband synthetics.
- Need to assess source, path, site response; produce a model and see how the user community reacts.

Fault sources:

- The Salt Lake City segment should include the connecting tear fault from the East Bench fault to the Warm Springs fault to be conservative; there is presently not enough data for the Quaternary Fault Parameters Working Group to provide a model.
- Surface fault ruptures can transfer/step over up to about 5 km, but a tear fault represents the simplest connection; using the Virginia Street fault is not practical due to its short mapped trace.
- At the southern end of the East Bench fault (Holladay stepover), connecting with the Cottonwood section is geometrically simple and geologically reasonable (more of a gap in mapped trace rather than a stepover).
- Need to determine fault sources to be included in addition to the Salt Lake City segment (e.g. West Valley fault zone, Oquirrh fault, Great Salt Lake faults, Provo segment).

Probabilistic UHMs must capture uncertainty.
Deterministic maps need to use the same source parameters - 30 bar stress drop (globally, 30-35 (40) average; up to ~90 or greater), because it affects PGA at higher frequencies.
Use empirical ground motions to get variables (stress drop) - PGA/PGV +/- factor of 2.
Rupture velocities – variable; locally supershear.
Dynamic rupture – V_s varies (0.8-0.9 of V_p).
Dynamic model - friction law stress distribution/range of stress drops (varies with depth; Archuleta uses depth-independent stress drops); roughness for kinematic.
Data indicate stress drop is consistent for range of earthquake magnitudes; little to no depth dependence.

The WFCVM (version 3c) should be used so results from different groups can be compared. No immediate plans to update CVM. Future updates need refinement/incorporation of Q(f), kappa.

Assessment of current state of urban hazard map components:

- Olsen/Roten model is close to what is needed for urban hazard maps; includes PGA, 0.2s SA, 1.0s SA on a grid incorporating nonlinear parameters.
- CMU group is modeling up to 2 Hz nonlinear and broadband response.
- Archuleta group will finalize dynamic model for 2 linear segments, and continue with multiple segments.

CMU group will finalize the present phase of their study by fall 2011:

- Using source from Archuleta, compare linear results.
- Verify non-linear response looking at reasonable material properties for Wasatch Front basins (likely from Olsen and others).
- Look into including broadband response from Archuleta and others.
- Need to incorporate low velocities in non-linear model.
- Need to reduce models domain to improve detail and computing times.

For USGS UHM products:

- Initially try broadband deterministic maps for the Salt Lake City segment.
    - M 7.0 earthquake
    - Salt Lake basin soil properties
- Need to validate linear results up to 2 Hz then try introducing non-linear results.
- Perform suite of simulations including lower Vs soils, 0.2s SA, 1.0s SA, PGA.

For USGS NEHRP RFP cycle: Bielak and Olsen proposal for collaborative work.
Ultimately will have 3 models each having the same domain extents to compare.
Maps can be hosted on UGS Web site; include links to different modeling results and input components.

SUMMARY OF THE FEBRUARY 14, 2012
UTAH GROUND SHAKING WORKING GROUP MEETING

Attendees:

Ivan Wong	Morgan Moschetti	Bob Smith
Greg McDonald	Qiming Liu	Kim Olsen
Mark Petersen	Jacobo Bielak	Kris Pankow
Bill Stephenson	Jim Pechmann	Walter Arabasz
Steve Bowman	Chris DuRoss	
Anthony Crone	Keith Koper	

The meeting convened at 8:30 am with introductions. Ivan Wong (working group facilitator) gave a brief overview of the working group history, objectives, and accomplishments, and summarized last year's priorities and this year's objectives:

- The Ground Shaking Working Group (GSWG) is at the point where urban seismic hazard maps (UHMs) need to be produced and released to the user community.
- The GSWG needs to determine what additional information is required at this point to produce UHMs; what components from the different models should be incorporated into the maps.
- An important objective is to develop a reliable three-dimensional model that captures basin effects and incorporates them into UHMs.
- How the maps are to be presented to users is important (such as via hard-copy maps, web-based, interactive, location coordinate input/output).

General considerations for UHMs:

- The UHMs need to be produced for periods up to 10s, and include peak ground acceleration (PGA), 0.2s, and 1.0s spectral accelerations (SAs) for building codes.
- The UHMs must incorporate uncertainties: epistemic can be approached by comparing results of the different models; aleatory are inherently more difficult to determine.
- The first version of UHMs will be for Salt Lake Valley with the intent of eventually expanding along the Wasatch Front urban corridor.
- Both deterministic and time-dependent maps should be produced for comparison. The Salt Lake Valley UHMs will be the first maps produced with a large weight given to time dependency.
- Both long- and short-period data need to be integrated – use nonlinear broadband synthetics.
- Source, path, and site-response effects need to be incorporated.

The different modeling groups at this point should be using Wasatch Front Community Velocity Model (WFCVM) version 3c (available at http://geology.utah.gov/ghp/consultants/geotechnical-data/cvm.htm), the same seismic source, and scenario earthquakes so their results are comparable; presently, there are no immediate plans to update the WFCVM, although some elements may need to be refined (such as Q[f], kappa, Vs30 layer).

Before the initial UHMs can be produced, broadband deterministic maps need to be created for the Salt Lake City segment M7.0 scenario that incorporates Salt Lake Valley soil properties. The linear results should be validated up to 2 Hz, then nonlinear results should be incorporated.

Kim Olsen - Review of Ground Motion Predictions from 0-10 Hz for M7 Earthquake on the Salt Lake City Segment

The final report has been submitted to the USGS; BSSA has published the low-frequency results (Roten and others; 2011) and BSSA publication of the high-frequency results is pending. Review of the San Diego State University (SDSU) broadband approach to ground-motion modeling:

- Employ the structure model from the WFCVM and spontaneous rupture simulation to produce a planar rupture model.
- Project the planar rupture model onto geologically-based fault geometry.
- Perform 3-dimensional finite-difference wave propagation simulation to generate 0-1 Hz synthetics for deriving 2s and 3s SA maps.
- Apply a broadband toolbox: High-frequency scattering operators for 0-10 Hz synthetics to derive < 1s SA and PGA maps.
- Deconvolute the high-frequency synthetics and incorporate non-linear soil parameters to get 0-10 Hz non-linear synthetics for producing SAs and PGAs along three profiles.
- Compare the derivative maps/profiles to the Next Generation of Ground-Motion Attenuation Model (NGA) derived results.

The 3-D model of the Salt Lake City segment is based on a simplified, geologically-based single trace and connecting the Cottonwood to East Bench and East Bench to Warm Springs step-overs. The trace is projected at depth using a geometry and dip from Bruhn and others (1992).

Four spontaneous rupture models with different hypocenter locations were used. Six scenario earthquakes were modeled; 5 deep, 1 shallow, all originating near non-conservative barriers; in this case, near both ends of the segment and the Cottonwood to East Bench step-over.

The SDSU results show a directionality effect on ground motions, with greater SAs near the ends of the ruptures. Averaged SAs from the six scenarios show ground motions drop off significantly sooner to the west of the fault than shown on NGA maps and recorded values at soil sites. The reason for the effect should be addressed before incorporation into the USHMs to determine if it is an artifact of the model or an accurate representation that should be reflected in the USHMs.

Non-linear soil response was incorporated using plasticity index (PI) values of 40 for Q01, 30 for Q02, and 0 for Q03 and rock. Comparisons of low frequency vs. broadband synthetics for higher accelerations show a non-linear diversion for broadband Q01 and creates better fit to NGA predictions.

Determination of site-dependent correction factors/third-order polynomials to fit one-dimensional simulation distribution is done for each site-response unit and frequency.

SDSU modeling results discussion:

The SDSU results appear to be usable for the UHMs. Presumably, more scenarios would produce a better fit/reduce uncertainties. Kim feels the six scenarios are converging on good results, but more would likely improve them. For comparison, ten scenarios were used for the Los Angeles basin model.

One issue is that the maps reflect circular patterns resulting from the Vs30 layer of the WFCVM (discrete circles around some Vs30 data points). Thus, the Vs30 component of the WFCVM may need refinement.

The USHMs should incorporate the modeling results to include basin effects, soil conditions, etc. Comparing different modeling results will get at epistemic uncertainty.
The U.S. Geological Survey (USGS) also needs to consider an approach similar to that used for the Seattle maps where the NGA results were adjusted at each site to better fit modeling results.

Qiming Liu - Curved Fault Dynamic Rupture Model for the Wasatch Fault Salt Lake City Segment

Brief review of previous work:

- The project involves modeling ground motions using a finite-element, meshed, dynamic model; stress for each point on the fault is needed (initial, yield, sliding friction, and final).
- Initially a single plane, 50 degree dipping fault was used, followed by a simple segmented source consisting of two sub-parallel, unconnected planes.
- Velocity strengthening was used for the upper ~3 km reducing final slip at the surface.

This year's work included more detailed fault models approaching the Salt Lake City segment geometry to see how the resulting ground motions evolve.

The most complex fault model is a simplified version of the trace used for the USGS National Seismic Hazard Maps (NSHM) that has the trace crossing northern Salt Lake Valley to the Warm Springs section and does not include the northern part of the East Bench fault.

Two rupture scenarios with hypocenters at either end of the fault were modeled to observe directivity effects.

Key observations include:

- Confirmation that fault geometry has a significant impact on rupture propagation.
- For the most complex fault model used, sensitivity of directivity to the kink at the Cottonwood fault to East Bench fault step-over was observed as it affects propagation and acts as a significant barrier; more so for north to south propagation.
- Smoothing out the Cottonwood fault to East Bench fault step-over kink results in ground motions getting through with high levels of ground shaking towards the end of the rupture.
- Using the same fault model as SDSU will likely result in more pronounced barrier effects at the East Bench tear fault.
- Taking the tear fault out and using a geologically-based fault trace with an East Bench fault to Warm Springs fault step-over may also have significant effect on wave propagation, but dynamic models can accommodate jumps.
- Comparing model peak ground velocities (PGVs) to NGA results show that the model values are generally lower and drop off more rapidly away from the fault.
- The results show that three-dimensional velocity structure impacts ground motions – low velocities amplify ground motions and increase the duration of ground shaking.
- Velocity strengthening near the free surface provides a physically-justified mechanism to reduce modeled slip to amounts more consistent with paleoseismic data.

Additional work is needed to finalize the results:

- Need to use more physically-based earthquake simulations up to 1 Hz.
- Need to use the same fault model and source scenarios as SDSU for comparison of results.

Morgan Moschetti - Earthquake Ground Motion Modeling with Kinematic Source Models: Preliminary low-frequency ground motions and effects of velocity perturbations to WFCVM

Kinematic fault model:

- Planar fault model fit through the NSHM trace for the Salt Lake City segment; 50 degree average dip.
- 45x20 km; hypocenter at 10 km along strike, 15 km down dip.
- One-dimensional velocity profile from the University of Utah Seismograph Stations.
- Different kinematic fault models can be rapidly generated by adjusting parameters.
- Constant slip velocity is applied to the fault model.

Material model:

- WFCVM is used as the reference model.
- Perturbed models are used for comparisons.

The ground motion results are significantly higher than the SDSU and University of California, Santa Barbara (UCBS) models; possibly due to the rupture model used. The observed correlation lengths for slip are at the high end for a M7 event.

Testing of the WFCVM:

- Perturbed velocities of sediments between R1 and R3 +/-10%.
- Used regional Vs model from surface wave tomography.
- Used wave propagation code from Carnegie-Mellon University (CMU) modeling group; min Vs = 200 m/s, max frequency = 1 Hz.

- Velocity perturbations to deep basin sediments affected the ground motions up to 0.5g above deeper parts of the basin mostly away from the fault; source predominantly affects ground motions above the fault plane.
- Correlations were observed between high ground motions and large, coherent slip patches on the fault model.
- The greatest effects on ground motions are caused by: 1) basin velocity structure away from the source, and 2) regional model structure near the source model. Replacing the regional model effectively decreases the moment with localized increases in ground motion.

Future work:

- Plan to finish low-frequency testing this year.
- Begin high-frequency synthetics (up to ~10 Hz).
- Incorporate a more realistic fault geometry.
- Set kinematic models to sample fault parameters.
- Randomize slip patches to capture uncertainty; can calculate variability based on correlation lengths with fault models.
- Perform runs using different slip models.

Jacobo Bielak - 3-D Ground Motion Linear and Nonlinear Simulations

Review of CMU modeling parameters:

- Single plane fault from UCSB (strike 153 degrees; dip 50 degrees).
- M6.8 scenario earthquake.
- Hypocenter: bottom center of plane.
- Vs min = 200 m/s.

For non-linear analysis:

- Soils with Vs ≤ 500 m/s are allowed to behave plastically.
- Material idealized to follow J2 yield criteria.

Some key observations include:

- Rapid ground-motion attenuation away from the fault on the hanging wall similar to other modeling groups results.
- Highest PGVs and PGAs along and near the fault trace on the hanging wall with a “foot” at the southern end; further work is needed to determine if the feature is real or a model artifact.
- No evidence of strong basin effects (in contrast to the SDSU results).
- PGA ratios show lower values for the nonlinear result near the fault on the hanging wall and northwest of the fault.
- Amplification occurs only in areas of low ground motion.
- On both PGV and PGA maps, circular artifacts from the WFCVM Vs30 layer are apparent.
- Near fault displacements are generally lower for the nonlinear results.

Rapid ground motion attenuation away from the fault may be due to the relative shallowness of the Salt Lake Valley; surface waves do not get generated to a large degree (fundamental, 1st and perhaps 2nd modes).
As wave frequency is increased, ground shaking may increase creating more dispersion.
More simulations are needed to improve results.
A more complex, geologically-based fault model should be incorporated.

Kris Pankow - Instrumentally Recorded Ground Motions M3 or Greater in the Utah Region since 2000

Project goals include:

- Measure PGA and PGV for earthquakes M3 and greater within 200 km of the Utah seismograph network.
- Sort and analyze the data by site-response unit.
- Compare the data to published ground-motion equations.

The records include:

- 164 earthquakes M_L 3.0 to 5.9.
- 1 event in Salt Lake Valley (2001; M_L 3.36).
- Largest event: M_L 5.9 Wells, NV (2008).

Data processing:
SAC transfer command is used to:

- Remove instrument response.

- Convert to acceleration and velocity.

Visual inspection of all waveforms is necessary to ensure:

- A five minute time window is dominated by the event, not other high-frequency spikes.
- There are no gaps.
- The signal-to-noise ratio is greater than about two.
- There is no visible trend (e.g. temperature, etc.).

Issues with the data:

- Some instruments are not orthogonal or NS/EW oriented.
- There are problems with some metadata/station response files.

Issues with comparisons to equations:

- Magnitude Mw vs $M_{L.}$
  - Distance term.
  - Small earthquakes cannot be used to calculate rupture planes.
- Hypocenter is very uncertain.
- Peak ground motion vs. orientation-independent ground motion.

UHM General Discussion

The GSWG is now at the point where UHMs need to be produced. Version 1 of the maps should probably be released within the next two years. The USGS needs to know what, if any, elements from the different models should be incorporated into the maps.

Once they are released, the GSWG needs to determine if the maps for the Salt Lake Valley should be improved upon/refined or if mapping should be expanded along theWasatch Front urban corridor to the north and/or south.

Issues to be addressed:

- How much uncertainty is in the WFCVM as a whole (non-linearity, velocity distribution model, directivity, directionality, etc), and whether or not it is usable as a foundation for the UHMs. USGS perturbation testing shows small changes in deep basin velocity can have a large effect on ground motions.
- Basin effects must be included in the maps; their significance to the final products needs to be determined.
- Assessment of the different modeling group results needs to be performed to determine if any of their components can be included in the UHMs in their present state. Not enough is known about some features (such as the "foot" on CMU maps), but probabilistic maps may filter out such features.

The SDSU results appear to be useable for the UHMs in their present state; additional modeling using more scenarios would likely lower the standard deviation improving them. Whether or not to use the source model that includes the East Bench to Warm Springs tear fault needs to be resolved as it is located in a critical area directly impacting downtown Salt Lake City. For the USHMs, it may be more conservative to include the tear fault, factoring in uncertainties. Sensitivity testing of the fault model both with and without the tear fault is also an option.

Presently, the different modeling groups results cannot be compared – let alone averaged – given the different sources and scenarios used.

Options for producing the first version of UHMs within the next two years:

- Option 1: Discontinue further modeling work at this point and incorporate SDSU results into USHMs. Focus future work to other parts of the Wasatch Front.
- Option 2: Continue to refine and test the other three models using the SDSU input parameters/conditions for comparison of results/possible inclusion in the UHMs.

Minimum model requirements for UHMs:

- Use a geologically-based fault model.
    - Use the SDSU model incorporating uncertainties.
    - The UCSB dynamic model could be used to test the sensitivity of the step-over/tear fault.
- Additional work needs to consider the roughly two-year time frame for producing the maps
    - Any additional modeling needs to consider timeframe including the USGS National Earthquake Hazards Reduction Program (NEHRP) request for proposals cycle for funding.
    - CMU can incorporate SDSU fault model and perform pseudo-dynamic modeling up to 4 Hz or collaborate with UCSB to use stochastic model results.
- Need better understanding of rapid ground-motion decay away from fault with respect to NGA predictions.
- The WFCVM needs additional testing to determine if it needs more work/refinement or is at a point where it can be considered usable/stable for now.

GSWG Priority Items

1. Through NEHRP funding, the GSWG has been working toward the development of urban seismic hazard maps for the Salt Lake Valley. Ground motion simulations for the Wasatch Front have been performed in the past several years also through NEHRP funding to evaluate the effects of the Salt Lake basin on ground motions. The WFCVM, another NEHRP-funded project, was used in the simulations. As part of UHM efforts, two issues have been raised in comparing the results of several ground-motion modeling approaches: (1) the effect of the East Bench-Warm Springs fault step-over on ground motions; and (2) an apparent drop off in the ground motions in the simulations relative to the NGA models west of the Wasatch fault. Research to address these issues is encouraged by the GSWG.
2. In addition to basin effects, the amplification and de-amplification effects of the shallow unconsolidated sediments need to be incorporated into the UHMs. Research to develop amplification factors to be used in the UHMs using empirical data and/or site response modeling is encouraged by the GSWG.

References

Bruhn, R., Gibler, P., Houghton, W., and Parry, W., 1992. Structure of the Salt Lake segment, Wasatch normal fault zone-Implications for rupture propagation during normal faulting, *in* Gori, P.L., Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500 A-J, p. H1-H25.

Roten, D., Olsen, K.B., Magistrale, H., Pechmann, J.C., and Cruz-Atienza, V.M., 2011, 3D simulations of M7 earthquakes on the Wasatch fault, Utah, Part I-Long-period (0-1 Hz) ground motion: Bulletin of the Seismological Society of America, Vol. 101, No. 5, p. 2045-2063.

Utah Liquefaction Advisory Group

2010 ULAG MEETING SUMMARY
Utah Liquefaction Advisory Group
Monday, February 8, 2010
Utah Department of Natural Resources Building, Room 2000

Steven Bartlett, Facilitator
Michael Hylland, UGS liaison

Members present:
Steven Bartlett, U of U
Anthony Crone, USGS
Travis Gerber, BYU
Grant Gummow, UDOT
Jim Higbee, UDOT
Michael Hylland, UGS
David Simon, SBI
Aurelian Trandafir, U of U
Les Youd, BYU

Guests:
M. Leon Berrett, USSC & SLCo.
Steve Bowman, UGS
Chris DuRoss, UGS
Dan Hinkley, U of U
John Masek, WBWCD
Greg McDonald, UGS
Mark Petersen, USGS
Robert Snow, URS
Ivan Wong, URS

INTRODUCTION, OVERVIEW OF ULAG OBJECTIVES, AND SUMMARY OF COMPLETED WORK

The meeting commenced at 1:00 p.m. Introductions included the announcement that Anthony (Tony) Crone has replaced Mark Petersen as the National Earthquake Hazards Reduction Program (NEHRP) Intermountain West Regional Coordinator; Mark will continue to be involved in NEHRP administration at the national level. Steve Bartlett then summarized the objectives of the Utah Liquefaction Advisory Group (ULAG), work undertaken in previous years, completed products (NEHRP deliverables), and work in progress.

ULAG objectives:

- Development of probabilistic liquefaction hazard maps (including liquefaction triggering, lateral spread, and seismically induced ground displacement) for the urban Wasatch Front counties
- Development of GIS programs for implementing the probabilistic hazard maps
- Establishment of a subsurface geotechnical database for public use (presently contains data from 930 boreholes)
- Education and public outreach

Work undertaken in previous years:

- Development of mapping techniques for under-sampled units, and uncertainty analysis (U of U graduate research [Dan Gillins]; see Technical Presentations below)
- Development of performance-based local-government geohazard ordinances (Draper City)
- Seismic assessment of Salt Lake Valley transportation network (UDOT; made use of the geotechnical database and developed a NEHRP site class map)
- Probabilistic liquefaction potential mapping of Salt Lake Valley (U of U graduate research [Michael Olsen, now at Oregon State University])

Completed products:

- Deterministic (M7) lateral spread displacement map for Salt Lake County
- Probabilistic liquefaction potential maps for Salt Lake County, 500- and 2500-yr return periods
- Deterministic (M7) ground settlement map for Salt Lake County
- Probabilistic ground settlement maps for Salt Lake County, 500- and 2500-yr return periods

Work in progress:

- Aggregated probabilistic liquefaction and lateral spread potential maps for Salt Lake County
- Downtown Salt Lake City ground-failure investigations (cone penetration testing [CPT]) (including along 400 South and the south side of the Salt Lake City Library block). Initial work completed, but more CPT soundings requested by ULAG to fill in data gaps.

Steve noted that the aggregated probabilistic liquefaction and lateral spread potential maps for Salt Lake County currently incorporate 2002 input data, but require updated 2008 U.S. Geological Survey strong motion estimates to be finalized. A 2010 NEHRP proposal to extend the 400 South CPT line eastward was not funded. No liquefaction research projects in Utah have received NEHRP funding since 2007.

TECHNICAL PRESENTATIONS

Ground-settlement Mapping for Salt Lake Valley
Dan Hinckley, University of Utah

Dan's work has produced three ground-settlement maps for Salt Lake Valley: a deterministic map based on a scenario M 7.0 earthquake, and two probabilistic maps (for 2% and 10% probability of exceedance [PE] in 50 years). The hazard categories shown on the deterministic map are based on a 15% exceedance threshold, meaning that at least 15% of the data fall within the range of values for the assigned hazard category (i.e., the majority of the data fall below the minimum value for the assigned hazard category). This approximates a mean value plus one standard deviation and is a conservative criterion. The 2% PE 50 yr map predicts a mean settlement value of 0.07 m; log-normal analyses predict mean settlement values of 0.06 m (zero-values excluded) and 0.03 m (zero-values included). Ivan Wong suggested that median, rather than mean, values would be appropriate for the log-normal analyses.

Mapping and Uncertainty Analysis of Liquefaction-induced Lateral Spread Displacements for Geotechnically Under-sampled Geologic Units
Dan Gillins, University of Utah

Dan was unable to attend this year's meeting, so his work was summarized by Steve Bartlett. Dan is developing a statistical approach to characterizing surficial geologic units for which little geotechnical data exist. The basic model being used to determine lateral spread displacements is the multiple linear regression model developed by Steve and Les Youd. One approach to modeling lateral spread displacements where geotechnical data are limited is to use a "reduced" model, where the variables for mean grain size and fines content are replaced by a soil classification term. Another approach is to use surrogate data from geologic units sampled elsewhere if those units have demonstrably similar geotechnical characteristics to the under-sampled units. Les Youd suggested that the use of CPT data in addition to, or as a substitute for, standard penetration testing (SPT) data should be looked into. He also recommended that aging effects be incorporated into the mapping method and suggested reviewing recent research by Ron Andrus of Clemson University. Dan's efforts to develop the mapping procedure and uncertainty analysis are presently being slowed by difficulties in obtaining funding to complete his research.

PRIORITIES FOR FY2011 RESEARCH

After extended discussion of NEHRP review panels' comments on last-year's proposals, ways to improve the chances for success of new NEHRP proposals, and other possible sources of funding for research, the ULAG members agreed on two priorities for FY2011:

- Investigation of the structural relation between the Warm Springs and East Bench faults (subsections of the Salt Lake City segment of the Wasatch fault zone) (proposed last year by U of U). New proposal should address review panel's recommendations to better resolve the location of identified faults by infill CPT soundings along 400 South, and location of a new CPT line south of 400 South. Tony Crone and Mark Petersen suggested that the proposal would benefit by establishing the work as a shared priority with the Utah Quaternary Fault Parameters Working Group, and by including letters of support from government agencies (e.g., the Utah Geological Survey).
- Establish a publicly-accessible electronic geotechnical database (in particular, Utah County UDOT data), and expand liquefaction-hazard mapping into Weber County (using Weber County as a test case for uncertainty analysis). John Masek (Weber Basin Water Conservancy District) expressed interest in providing support (including funding) for liquefaction research in Weber County.

The meeting was adjourned at 4:00 p.m.

2011 ULAG MEETING SUMMARY
Utah Liquefaction Advisory Group
Tuesday, February 15, 2011
Utah Department of Natural Resources Building, Room 1010

Steve Bartlett, Facilitator
Mike Hylland, UGS liaison

Members present:
Steve Bartlett, U of U
Tony Crone, USGS
Grant Gummow, UDOT
Mike Hylland, UGS
David Simon, SBI
Bill Turner, Earthtec
Les Youd, BYU

Guests:
Doug Bausch, FEMA
Zhenzhong Cao, BYU
Chris DuRoss, UGS
Dan Gillins, U of U
Dan Hinkley, IGES
Rich Giraud, UGS
Alan Taylor, Taylor Geotechnical

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ULAG objectives:
- Development of probabilistic liquefaction hazard maps (including liquefaction triggering, lateral spread, and seismically induced ground settlement) for the urban Wasatch Front counties.
- Development of GIS programs for implementing the probabilistic hazard maps.
- Establishment of a subsurface geotechnical database for public use.
- Education and public outreach.

Completed products:
- Deterministic (M7) lateral spread displacement map for Salt Lake County.
- Deterministic (M7) ground settlement map for Salt Lake County.
- Probabilistic ground settlement maps for Salt Lake County, 500- and 2500-yr return periods.
- Probabilistic liquefaction potential maps for Salt Lake County, 500- and 2500-yr return periods.

Work in progress:
- Aggregated probabilistic liquefaction and lateral spread potential maps for Salt Lake County.
- Lateral spread hazard mapping in Weber County, and development of a statistical approach to characterizing surficial geologic units for which little geotechnical data exist (under-sampled units).

Steve noted that the aggregated probabilistic liquefaction and lateral spread potential maps for Salt Lake County currently incorporate 2002 input data, but require updated 2008 U.S. Geological Survey strong motion estimates to be finalized. A 2011 National Earthquake Hazards Reduction Program (NEHRP) proposal to expand liquefaction-hazard mapping into Weber County was not funded; however, partial funding provided by the Weber Basin Water Conservancy District allowed Dan Gillins to begin mapping in Weber County and continue development of an approach for characterizing under-sampled units (see technical presentation summary below). No liquefaction research projects in Utah have received NEHRP funding since 2007.

TECHNICAL PRESENTATIONS

Liquefaction in the M 4.5 Randolph, Utah, Earthquake
Chris DuRoss, Utah Geological Survey (UGS)

Chris summarized the results of a brief field reconnaissance following the M_w 4.5 earthquake that occurred on April 15, 2010, near Randolph in northern Utah. Numerous sand boils were observed in Holocene Bear River floodplain alluvium along a 1-km stretch of the river in the epicentral area, indicating that this earthquake is one of the smallest instrumentally recorded earthquakes to generate liquefaction. The liquefaction is attributed to highly susceptible sediments near the earthquake's epicenter. However, Chris and Kristine Pankow (University of Utah Seismograph Stations) are investigating the possibility that anomalously high ground motions also contributed to the liquefaction.

Liquefaction-hazard Mapping in Weber County
Dan Gillins, Ph.D. Candidate, University of Utah

Dan summarized his lateral spread displacement mapping in Weber County, focusing on the development of an approach for characterizing under-sampled surficial geologic units. The basic model being used to determine lateral spread displacements is the multiple linear regression model developed by Bartlett and Youd. Available borehole data for Weber County include little to no information on fines content and mean grain size (F_{15} and $D50_{15}$ terms, respectively, in the Bartlett and Youd model). In a "reduced" model, these two terms are simply removed from the full model, but sensitivity analysis indicates significant over- and under-prediction relative to the full model. In a "modified" model, coefficients associated with soil names (derived from soil descriptions; e.g., gravel, poorly graded sanded, silty sand, and silt) are used as a proxy for fines-content and mean-grain-size terms, and sensitivity analysis indicates improvement in R^2 over the "reduced" model. Dan also indicated that CPT data (tip resistance and sleeve friction) can be used to estimate soil type. Difficulties in obtaining funding for Dan's work are presenting challenges to completion of the mapping and uncertainty analysis.

ADDITIONAL PRESENTATION

BYU-IEM Collaborative Research
Les Youd, Brigham Young University

Les summarized a recent trip to China to meet with representatives of the Institute of Engineering Mechanics (IEM) to discuss possibilities for collaborative liquefaction research and mapping. The trip came about partly as the consequence of graduate research by Zhenzhong Cao (presently at BYU) conducted after the 2008 M_s 8.0 Wenchuan earthquake and involving dynamic penetrometer testing of liquefied gravels. Les is returning to China in May 2011 to follow up on proposed work, and indicated that the collaboration may present opportunities for other researchers in Utah.

REVIEW OF FY2011 NEHRP PROPOSAL AND PANEL COMMENTS

Steve Bartlett summarized the review panel comments and ultimate outcome of last year's NEHRP proposal to expand liquefaction-hazard mapping into Weber County. Although the proposal received favorable comments from the review panel, both in terms of technical merit and budget, the final ranking of the proposal resulted in it falling just below the NEHRP funding-level cut-off. The idea of resubmitting the proposal this year, with expansion of mapping into Davis County, was met favorably by the group. As a point of information, Tony Crone reviewed the President's budget proposal, which includes a $2 million cut to the USGS External Grants Program (which would translate into a 10% cut to the Earthquake Hazards Program).

MISCELLANEOUS PLANNING AND PRIORITIES FOR FY2012

The group discussed two new areas of activity for FY2012: (1) publication of the Salt Lake County liquefaction hazard maps, and (2) expanding the scope of the 2012 ULAG meeting to include an education/tech transfer/outreach component. The group also discussed the Weber County liquefaction hazard mapping as a continuing research priority. No additional CPT work is currently planned for the Salt Lake City Library Block or southern extension of the Warm Springs fault.

The group also discussed the relative lack of subsurface geotechnical data outside of the central Wasatch Front (i.e., Salt Lake and Utah Counties), and raised the issue of extensive data held by the LDS Church but which the church has been reluctant to make available to third parties. Les commented that he occasionally provides *pro bono* consulting services for the church, and offered to follow up on the data-availability issue with the church's Building Department.

Summaries of the planning and priority discussions are as follows:

Publication of the Salt Lake County Liquefaction Hazard Maps

- The maps need to be finalized.
- The authors need to determine which liquefaction maps to publish.
- The group would like to have a model liquefaction ordinance available for local government staff; Bartlett and Simon expressed interest in generating a draft ordinance.
- The group is in favor of having the UGS publish the maps. UGS in-house support would likely need to include cartographic, GIS, editorial, and press release expertise.
- David Simon noted that one of the initial goals of the working group is dissemination of the maps to local municipalities and encouraging the municipalities to incorporate the maps into their respective ordinances. Currently, only Draper City has done that. In that regard, David suggested a formal presentation and explanation of the maps to municipalities at the 2012 ULAG meeting, or possibly at the 2012 AEG national meeting in Salt Lake City. David felt that educating the municipalities, a goal of the working group, is more important than educating local consultants, which is also important but NOT a goal of the working group. Without adoption by local municipalities, the maps are only academic in nature.

Expanding the Scope of the 2012 ULAG Meeting

- The 2012 ULAG meeting should be scheduled for a full day and should include an education/tech transfer/outreach component, to include the appropriate decision makers from local municipalities.
- The morning would consist of a workshop featuring a keynote address and possibly other invited talks from highly regarded liquefaction researchers. The afternoon would consist of the traditional ULAG meeting.

- If the Salt Lake County liquefaction hazard maps are published, the morning workshop would focus on showing local government representatives how to use the maps and implement a liquefaction ordinance.
- The group also considered the possibility of a workshop coinciding with map publication independent of the 2012 ULAG meeting.
- If the Salt Lake County liquefaction hazard maps are not published, the morning workshop would focus on technical liquefaction issues for consultants.
- The primary goal of the morning workshop is to provide outreach.

Weber County Liquefaction Hazard Mapping

- Steve Bartlett will resubmit the NEHRP grant proposal for Weber County liquefaction hazard mapping. Parts of Davis County will likely be included in the new proposal. Based on current discussions of the federal budget, funding from the USGS does not look promising.
- The current liquefaction hazard mapping being funded by the Weber Basin Water Conservancy District and Pacific Corp in Weber County will be completed.
- Maps for the remainder of Weber County may have to be completed without funding.

The meeting was adjourned at 4:45 p.m.

SUMMARY
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
KICKOFF MEETING
Wednesday/Thursday, February 10 & 11, 2010
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

WELCOME AND INTRODUCTION

Bill Lund (Utah Geological Survey [UGS]) Working Group on Utah Earthquake Probabilities (WGUEP) Coordinator called the WGUEP kickoff meeting to order at 8:00 a.m. After welcoming remarks and introductions of WGUEP members (see attachment 1), Bill turned the meeting over to Ivan Wong (URS Corporation; WGUEP Chairperson) who discussed the need for the working group, defined a proposed study region, and presented a tentative scope of work and schedule for future meetings. Ivan also discussed the Senior Seismic Hazard Analysis Committee (SSHAC) guidelines and their possible use as a model for conducting WGUEP activities.

Summary of Ivan's Presentation

Information on past earthquakes along the Wasatch fault and regional seismicity and geodetic data are now sufficiently robust to provide the basis for making probabilistic estimates of future large earthquakes within the Wasatch Front area. The methodologies necessary to estimate probabilities have been developed and refined by the various California working groups, and their experience can now be applied in Utah. There are both critical scientific and hazard-mitigation needs for a formal, consensus-based estimate of earthquake probabilities along the Wasatch Front. Wasatch Front urban hazard maps are planned by the U.S. Geological Survey (USGS) and time-dependent probabilities can be incorporated into the probabilistic seismic hazard analyses (PSHA) that will form the basis of those maps. Time-dependent hazard estimates will also eventually be incorporated into the USGS National Seismic Hazard Maps and the National Earthquake Hazard Reduction Program building code provisions. An earthquake forecast can also be directly incorporated into site-specific PSHAs for the design and safety evaluation of critical structures and facilities. Additionally, a consensus-based estimate of earthquake probabilities for the Wasatch Front developed and reviewed by the earth science community can be incorporated into public policy that will drive greater and more sustained earthquake mitigation efforts in Utah.

Ivan presented a proposed Wasatch Front study region map that showed the Quaternary–active faults in the region that would be considered in the WGUEP earthquake forecast (figure 1). The map, with minor boundary changes on its north, west and east sides, was later adopted as the WGUEP study region.

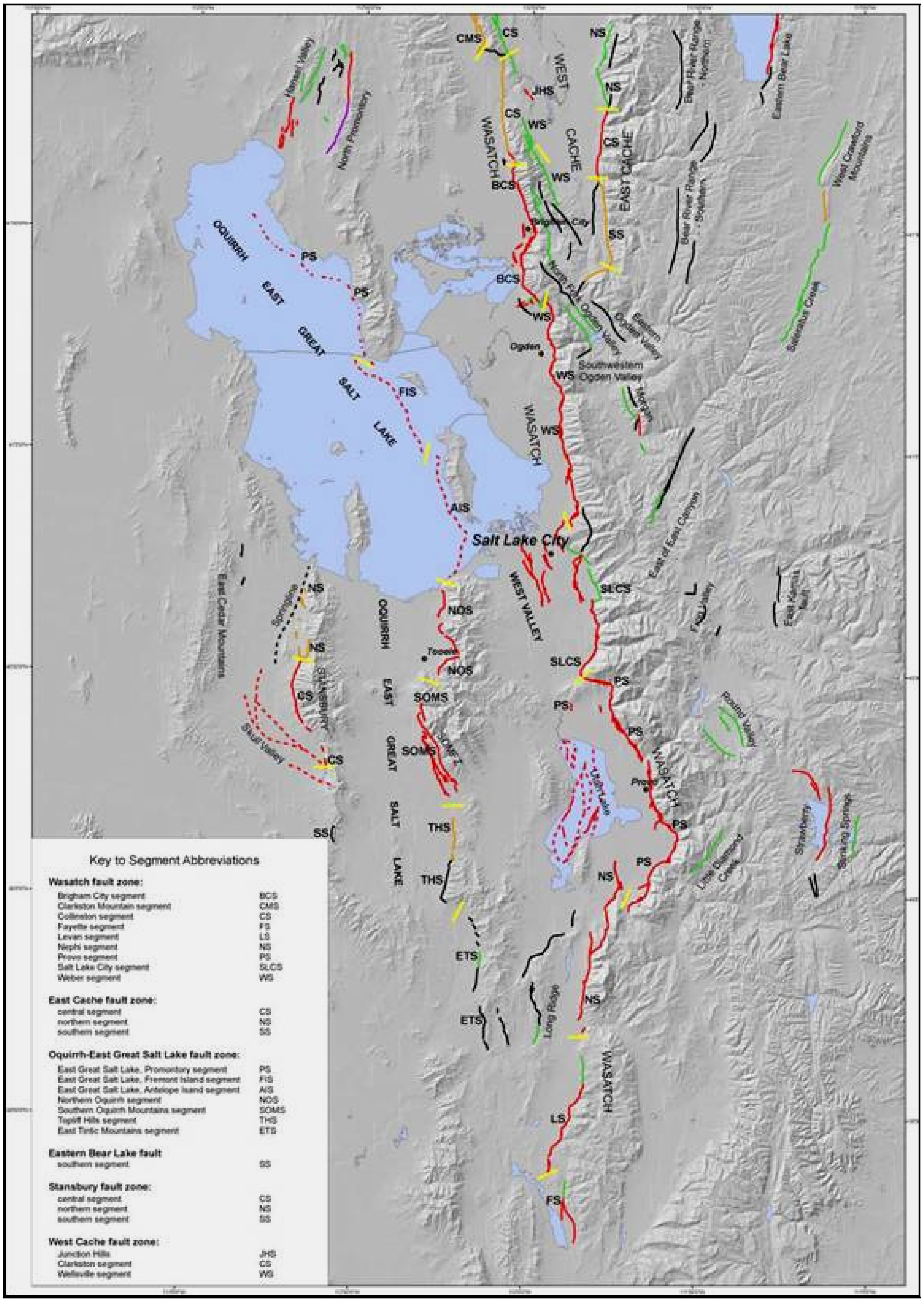


Figure 1. Map of proposed Wasatch Front study region showing Quaternary-active faults to be considered in the WGUEP earthquake forecasts. This map with boundary changes to the west (western boundary moved eastward to the west edge of Great Salt Lake) and east (eastern boundary moved westward to the easternmost extent of back-valley faults) was later adopted as the WGUEP study region.

Ivan briefly described the difference between time-independent and time-dependent earthquake forecasts. In a time-independent forecast, the probability of each earthquake rupture is completely independent of the timing of all others. Time-dependent models are based on the concept of stress renewal – the probability of a fault rupture drops immediately after a large earthquake releases tectonic stress on the fault and rises again as the stress is regenerated by continuous tectonic loading. The WGUEP forecast will include both time-dependent and time-independent probabilities for the Wasatch fault and other faults in the Wasatch Front region (e.g., East Great Salt Lake fault) depending on data availability; the forecast will also address background earthquakes.

An approach similar to that taken by the various California working groups will be followed in preparing the Wasatch Front earthquake forecast. The WGUEP will convene a series of workshops and meetings over a two-year period to review and develop forecast model components. Four models will be implemented in the forecast process: (1) fault model, (2) deformation model, (3) earthquake rate model, and (4) probability model. Epistemic uncertainties in all model input parameters will be explicitly addressed by the WGUEP. Ivan proposed that the WGUEP follow a SSHAC Level 2 process while performing their work. That proposal resulted in considerable discussion among the WGUEP members familiar with the SSHAC guidelines, with most members expressing reservations about following a formal SSHAC process. In the end, it was agreed that the WGUEP would follow the "spirit" of the SSHAC Level 2 guidelines, but would not aspire to formal SSHAC certification.

The WGUEP process will include calculating the probability of a large earthquake ($M \geq 6.5$) in the Wasatch Front region for a range of intervals varying from annually to 100 years. This is in contrast to the California working groups which emphasized a 30-year probability, which is appropriate given the high slip rate along the San Andreas transform plate boundary. However, deformation rates along the Wasatch Front are an order of magnitude lower than in California and the WGUEP will therefore of necessity consider longer intervals. The earthquake forecast will also include earthquakes in the $5 \leq M \leq 6.5$ range to account for potentially damaging background earthquakes. Earthquake probabilities to be estimated include: (1) segment-specific for the Wasatch fault, (2) total for the Wasatch fault, (3) fault-specific for other major faults in the area, and (4) total for the Wasatch Front region. The final WGUEP earthquake forecast will undergo a formal internal USGS review, and will also be sent to the National Earthquake Prediction Council for review and comment. Media release of the WGUEP results will be handled by the UGS. Project results will be presented at meetings for the general public and at professional and scientific society meetings.

Ivan ended his presentation by presenting a WGUEP meeting schedule and general scope of work for the next two years (table 1). He emphasized that the WGUEP has a two-year time limit and that the resulting earthquake forecast is meant to be based on available data. Future, more refined forecasts will undoubtedly follow this initial effort as they did in California, but the current WGUEP process represents an essential first step in that longer process.

Table 1. WGUEP meeting schedule and general scope of work.

Meeting	Purpose
1	Kickoff: Review WGCEP process and WGUEP scope of work.
2	Develop rupture scenarios for the Wasatch fault.
3	Develop time-dependent and independent recurrence rates for the Wasatch fault.
4	Develop time-independent recurrence rates for other Wasatch Front faults.
5	Review preliminary earthquake probability calculations.
6	Review and adopt final results.

TECHNICAL PRESENTATIONS

Following Ivan's presentation, the remainder of the meeting on Wednesday (February 10) and much of the meeting on Thursday (February 11) were devoted to technical presentations relevant to the start up of the WGUEP process. The PowerPoint slide shows accompanying each of the technical presentations below are available at http://geology.utah.gov/ghp/workgroups/wguep.htm.

Wednesday, February 10

• Overview of UCERF2[1]	Mark Petersen, USGS
• Overview of WGCEP02[2]	David Schwartz, USGS
• Overview of Wasatch Fault	Chris DuRoss, UGS
• Overview of Forecast Model Inputs	Ivan Wong, URS Corp.
• Overview of UQFPWG[3] Model	Bill Lund, UGS
• Time-Dependent Earthquake Recurrence Studies Along the Wasatch Front, Utah	Susan Olig, URS Corp.

Thursday, February 11

• Overview of University of Utah Earthquake Catalog	Jim Pechmann, UUSS
• Overview of Seismicity, Background Earthquakes, and Modeling Earthquake Rates in Utah	Walter Arabasz
• Overview of Geodetic Data	Bob Smith, UUGG
• Incorporation of Geodetic Rates into Forecast	Bob Smith, UUGG

[1]Uniform California Earthquake Rupture Forecast Version 2, [2]Working Group on California Earthquake Probabilities 2002, [3]Utah Quaternary Fault Parameters Working Group

ISSUES RAISED DURING THE MEETING

Several issues were raised during the presentations that will need to be addressed during the course of the project:

- Uncertainty still remains regarding segment boundaries on the Wasatch fault. Based on trench data, apparent spillover from one segment to another, e.g., 1983 Borah Peak, appears to have also occurred on the Wasatch fault.

- Do the Provo and Nephi segments, or portions of these segments, rupture coseismically?

- The Brigham City segment early Holocene earthquake record appears to be still incomplete. This incompleteness will need to be addressed in assessing recurrence along this segment.

- Questions remain regarding the timing, recurrence, and extent of mid- to late-Holocene earthquakes on the Weber segment. Discussions with the original paleoseismic investigators may help resolve these uncertainties.

- The relation of the West Valley fault zone (WVFZ) to the Salt Lake City segment (SLCS) of the Wasatch fault zone remains uncertain. Hopefully, upcoming UGS investigations on the SLCS and WVFZ will reduce the uncertainties.

- Over what time period is the paleoseismic record complete for the Nephi segment? Are the three most recent (late Holocene) earthquakes temporally clustered?

- What is the best coefficient of variation (COV) or range of COVs to be used in the time-dependent models?

- Is the strand of the Wasatch fault located east of Salt Lake City and the East Bench fault of the SLCS at the base of the range active?

- What is the best way to convert horizontal geodetic extension rates to fault dip slip rates?

- The magnitudes of pre-instrumental earthquakes within the Wasatch Front, particularly those near Salt Lake City need to be revisited. Current estimates rely on the Gutenberg-Richter frequency-magnitude relation or on Modified Mercalli intensity estimates.

TASK LIST

Following the end of technical presentations on Thursday, Ivan summarized the results of the two days of meetings, discussed topics for future meetings, and reviewed the assignments made for various working group members. Current assignments include:

1. Re-examine background seismicity recurrence with an emphasis on pre-instrumental seismicity. Note that the region we have defined for the forecast may not exactly match the region for which the recurrence has been calculated (Walt and Jim).

2. Write up the calculation of COV for the Wasatch fault (Susan).

3. Perform OxCal analyses of remaining segments of the Wasatch fault (Chris, Susan, Tony, Steve, and Bill).

4. Comparison of the extensional strain rates from the geodetic and slip rate data (Mark).

5. Develop the list of faults in the forecast region (Bill).

6. Create Strawman rupture scenarios for the Wasatch fault (Chris).

7. Complete report on the megatrench and distribute to other working group members (Susan).

8. Establish a password protected website for the working group (Steve Bowman).

The next WGUEP meeting is scheduled for July 14-15, 2010 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, UGS
Bill Lund, UGS, Coordinator
Susan Olig, URS Corporation
James Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
Dave Schwartz, USGS
Bob Smith, UUGG
Ivan Wong, URS Corporation, Chair

*Steve Bowman, UGS Liaison

ATTACHMENT 2
AGENDA
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Wednesday/Thursday, February 10 & 11, 2010
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

10 February 2010

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome and Introductions	Bill Lund
8:15 – 9:00	Purpose, Tentative Scope of Work, SSHAC Process, and Schedule	Ivan Wong
9:00 – 9:30	Overview of UCERF2	Mark Petersen
9:30 – 10:15	Issues Associated with UCERF2	David Schwartz
10:15 – 10:30	Break	
10:30 – 11:00	Discussion on UCERF2	Mark Petersen/David Schwartz
11:00 – 12:00	Overview of Wasatch Fault	Chris DuRoss
12:00 – 1:00	Lunch	
1:00 – 2:00	Overview of Forecast Model Inputs	Ivan Wong
2:00 – 3:00	Overview of Utah Quaternary Fault Working Group Model	Bill Lund
3:00 – 3:15	Break	
3:15 – 4:15	Review of Wasatch Time-Dependent Probabilities	Susan Olig
4:15 – 5:00	Discussion	
5:00	Adjourn	

11 February 2010

7:30 – 8:00	Continental Breakfast	
8:00 – 9:00	Overview of Seismicity Catalog	Walter Arabasz/Jim Pechmann
9:00 – 9:30	Incorporation of Background Seismicity into Forecast	Walter Arabasz/Jim Pechmann
9:30 – 9:45	Break	
9:45 – 10:45	Overview of Geodetic Data	Bob Smith
10:45 – 11:30	Incorporation of Geodetic Rates into Forecast	Bob Smith
11:30 – 12:30	Lunch	
12:30 – 3:00	Issues (integration of geodetic data, segmentation, multi-segment rupture, recurrence models, etc.)	Ivan Wong
3:00 – 3:15	Break	
3:15 – 4:00	Path Forward	All
4:00	Adjourn	

WGUEP Members

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

SUMMARY
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
SECOND MEETING
Wednesday/Thursday, July 21 & 22, 2010
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

WELCOME AND INTRODUCTION

Bill Lund (Utah Geological Survey [UGS]) Working Group on Utah Earthquake Probabilities (WGUEP) Coordinator called the second WGUEP meeting to order at 8:00 a.m. After welcoming remarks, introductions of WGUEP members (attachment 1), and a review of the meeting's two-day agenda (attachment 2), Bill turned the meeting over to Ivan Wong (URS Corporation; WGUEP Chairperson). Ivan recapped the WGUEP process, summarized issues raised and tasks assigned at the WGUEP kickoff meeting in February, and reviewed the six-meeting schedule established to complete the WGUEP process.

Summary of Ivan's Presentation

Issues Raised Last Meeting

- Uncertainty still remains regarding segment boundaries on the Wasatch fault. Based on trench data, apparent spillover from one segment to another (e.g., 1983 Borah Peak) may have occurred on the Wasatch fault during past surface ruptures.

- This observation raises the question: "Do the Provo and Nephi segments, or portions of these segments, rupture coseismically?"

- The Brigham City segment: the early Holocene earthquake record appears to still be incomplete. This incompleteness will need to be addressed by assessing recurrence along this segment (*addressed by subsequent OxCal analysis*).

- Questions remain regarding the timing, recurrence, and extent of mid- to late-Holocene earthquakes on the Weber segment. Discussions with the original investigators who conducted the initial studies on this segment may help resolve these uncertainties (*addressed by subsequent OxCal analysis*).

- Over what time period is the paleoseismic record complete for the Nephi segment? Are the three most recent (late Holocene) earthquakes temporally clustered?

- What is the best coefficient of variation (COV) or range of COVs to be used in the time-dependent models?

- The relation of the West Valley fault zone (WVFZ) to the Salt Lake City segment (SLCS) of the Wasatch fault zone (WFZ) remains uncertain. Upcoming UGS investigations on the SLCS and WVFZ are expected to reduce this uncertainty (*paleoseismic investigations currently underway*).

- Is the strand of the Wasatch fault located east of Salt Lake City and the East Bench fault of the SLCS at the base of the range active? (*existing mapping would indicate not active*)

- What is the best way to convert horizontal geodetic extension rates to fault dip-slip rates?

- The magnitudes of pre-instrumental earthquakes within the Wasatch Front, particularly those near Salt Lake City, need to be revisited. Current magnitude estimates rely on Modified Mercalli Intensity estimates and it may be possible to refine the magnitudes using a more current magnitude-maximum intensity model.

Tasks Identified Last Meeting

- Re-examine background seismicity recurrence with an emphasis on pre-instrumental seismicity. Note that the region we have defined for the forecast may not exactly match the region for which the recurrence has been calculated – Walter Arabasz and Jim Pechmann.

- Write up the calculation of COV for the Wasatch fault – Susan Olig.

- Perform OxCal analyses of remaining segments of the Wasatch fault – Chris DuRoss, Susan Olig, Tony Crone, Steve Personius, and Bill Lund (*done*).

- Compare geodetic extensional strain rates with geologic slip rates – Mark Peterson.

- Develop a list of Quaternary-active faults in the forecast region – Bill Lund (*done*).

- Create strawman rupture scenarios for the Wasatch fault – Chris DuRoss (*underway*).

- Complete megatrench report and distribute to other working group members – Susan Olig.

- Establish a password protected website for the working group – Steve Bowman (*done*).

WGUEP Schedule

The original six-meeting schedule presented at the kickoff meeting in February is presented below. Ivan noted that to ensure a smooth flow of data to the WGUEP process, it may be necessary to modify future meeting topics, but that the intention at this point is to maintain the six-meeting schedule.

Table 1. WGUEP meeting schedule and general scope of work.

Meeting	Purpose
1	Kickoff: Review WGCEP process and WGUEP scope of work.
2	Develop rupture scenarios for the Wasatch fault.
3	Develop time-dependent and independent recurrence rates for the Wasatch fault.
4	Develop time-independent recurrence rates for other Wasatch Front faults.
5	Review preliminary earthquake probability calculations.
6	Review and adopt final results.

TECHNICAL PRESENTATIONS

Following Ivan's presentation, the remainder of the meeting on Wednesday (July 21) and much of the meeting on Thursday (July 22) was devoted to technical presentations relevant to the WGUEP process. The PowerPoint slide shows accompanying each of the technical presentations below are available at http://geology.utah.gov/ghp/workgroups/wguep.htm.

Wednesday, July 21

- Methodology Summary - Use of OxCal and MATLAB to refine earthquake timing and recurrence for the five central Wasatch fault segments – Chris DuRoss

- OxCal earthquake timing and MATLAB recurrence interval models for the five central Wasatch fault segments (earthquake pdfs, individual intervals between events, average segment recurrence intervals, MRE timing) – Chris DuRoss, Steve Personius, Tony Crone, Susan Olig

- Summary and discussion Wasatch fault earthquake timing and recurrence intervals – Chris DuRoss

- Introduction to rupture scenario models - Bay Area faults vs. Wasatch fault - David Schwartz

- Presentation of Wasatch fault strawman rupture scenario models – Chris DuRoss

Thursday, July 22

- Presentation of Wasatch fault strawman rupture scenario models continued

- Earthquake timing and slip-rate information for Wasatch fault end segments – Mike Hylland

- Other faults in the Wasatch Front study region – how many, how big, how fast – Bill Lund (Review by working group resulted in elimination of 54 faults and identified an additional 10 that might be eliminated upon further investigation, attachment 3)

NEW ISSUES RAISED DURING THE MEETING

New issues raised during the presentations that will need to be addressed during the course of the project include:

- Geodetic extension rates are higher than vertical (geologic) slip rates – how should the geodetic rates be weighted?

- How should recurrence intervals for the WFZ be calculated? Should only closed intervals be used, or should the elapsed time since the most recent earthquake be included as an interval?

- Are there faults other than the WFZ (e.g., the Great Salt Lake or Oquirrh fault zones) that should be modeled in a time-dependent manner?

- What is the best method(s) for calculating values of M_{max} for faults in the study region?

- What is the best method/model for moment balancing the Wasatch fault segments/other faults?

- What slip-rate values should be assigned to the Wasatch fault end segments? (those segments that do not have evidence of multiple Holocene surface ruptures)

- Ten low slip rate faults in the study area require further scrutiny to determine if they should be included in this study or excluded as contributing too little to overall earthquake probability.

TASK LIST

Following the end of technical presentations, Ivan summarized the results of the two days of meetings, and presented a list of tasks to be performed prior to the next WGUEP meeting. The tasks include:

1. Complete strawman rupture scenarios for the Wasatch fault – Chris DuRoss, Steve Personius, Tony Crone, Susan Olig, Bill Lund

2. Explore different approaches to calculate earthquake recurrence – Ivan Wong and Nico Luco

3. Compare horizontal extensional strain rates with geologic (vertical) slip-rate data for the Wasatch Front study region (What is the best way to convert horizontal geodetic extension rates to fault dip-slip rates?) – Mark Peterson

4. Determine the best approach(es) for calculating M_{max} (length, displacement, area) for study area faults – ?

5. Develop a methodology for moment balancing normal faults (create moment-balance model for the Wasatch fault) – Mark Peterson plus USGS group

6. Updates on the new SLCS and WVFZ trench data – Chris DuRoss and Mike Hylland

7. Update on Wasatch Front background earthquake recurrence rates – Walter Arabasz and Jim Pechmann

8. Evaluate "maybe" faults (10 faults in the Wasatch Front region on the bubble for inclusion in this study) – Bill Lund

NEXT MEETING

The next WGUEP meeting is scheduled for December 1-2, 2010 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, UGS*
Bill Lund, UGS, Coordinator*
Susan Olig, URS Corporation*
James Pechmann, UUSS*
Steve Personius, USGS*
Mark Petersen, USGS*
Dave Schwartz, USGS*
Bob Smith, UUGG
Ivan Wong, URS Corporation, Chair*
Steve Bowman, UGS Liaison to WGUEP

*Attended meeting 2

ATTACHMENT 2
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING AGENDA
Wednesday/Thursday, July 21 & 22, 2010
Utah Department of Natural Resources Building, Room 2000
1594 West North Temple, Salt Lake City

<u>Wednesday July 21</u>

7:30 a.m.	Continental breakfast
8:00 a.m.	Methodology Summary - Use of OxCal and MATLAB to refine earthquake timing and recurrence for the five central Wasatch fault segments – Chris DuRoss
8:30 a.m.	OxCal earthquake timing and MATLAB recurrence interval models for the five central Wasatch fault segments (earthquake pdfs, individual intervals between events, average segment recurrence intervals, MRE timing) – Chris DuRoss, Steve Personius, Tony Crone, Susan Olig
10:00 a.m.	Break
10:30 a.m.	OxCal earthquake timing and MATLAB recurrence interval models for the five central Wasatch fault segments continued
12:00 p.m.	Lunch
1:00 p.m.	Summary and discussion Wasatch fault earthquake timing and recurrence intervals – Chris DuRoss
2:00 p.m.	Introduction to rupture scenario models - Bay Area faults vs. Wasatch fault - David Schwartz
2:30 p.m.	Break
3:00 p.m.	Presentation of Wasatch fault strawman rupture scenario models – David Schwartz, Chris DuRoss
4:30	Wrap up – Ivan Wong
5:00 p.m.	Adjourn

<u>Thursday July 22</u>

7:00 a.m.	Continental breakfast
7:30 a.m.	Final rupture scenario model selection and weighting by working group members - moderator Chris DuRoss

9:00 a.m.	Earthquake timing and slip-rate information for Wasatch fault end segments – Mike Hylland
10:30 a.m.	Break
11:00 a.m.	Summary and discussion of Wasatch fault end segment data - select end segment parameters for probability model – Mike Hylland
12:00 p.m.	Lunch
1:00 p.m.	Other faults in the Wasatch Front study region – how many, how big, how fast – Bill Lund
2:30 p.m.	The way forward – Ivan Wong
3:00 p.m.	Adjourn

ATTACHMENT 3
Wasatch Front Study Area Faults Other than the Wasatch Fault
Requiring Additional Investigation for Inclusion in Study
or
Eliminated from Further Study Consideration

Faults Requiring Additional Evaluation

East Cache fault zone northern section
Joes Valley fault zone east fault
Joes Valley fault zone intergraben faults
Joes Valley fault zone west faults
Long Ridge Northwest side
Long Ridge West side
Ogden Valley North Fork
Ogden Valley Southwest Margin faults
Stinking Springs
Sublette Flat

Faults Eliminated from Further Study Consideration

Almy
Bald Mountain
Bear River Range faults
Blue Springs Hills faults
Cedar Mountains - East side
Cedar Valley - South side
Clover fault zone
Cricket Mountains - North end
Deseret
Dolphin Island fracture zone
Duncomb Hollow
East Kamas
East Lakeside Mountains fault zone
East Side Sublette Range faults
Elk Mountain
Frog Valley
Gooseberry graben
Hansel Mountains - East side
Hansel Valley - Valley floor
Hyrum
Japanese and Cal Valley faults
Lakeside Mountains - West side
Little Diamond Creek
Lookout Pass
Mantua area faults
North Bridger Creek
North Promontory Mountains
Ogden Valley NE Margin faults
Pavant faults
Pleasant Valley fault zone - Dry Valley graben
Pleasant Valley fault zone - graben
Pleasant Valley fault zone - unnamed faults
Puddle Valley fault zone
Raft River Mountains
Round Valley faults
Ryckman Creek
Sage Valley
Saint John Station fault zone
Saleratus Creek
Sheeprock Mountains
Simpson Mountains faults
Snow Lake graben
Southern Joes Valley fault zone
Spring Creek
Sugarville Area faults
The Pinnacle
Valley Mountains monocline
Vernon Hills fault zone
Wasatch monocline
West Pocatello Valley
Western Bear Valley faults
White Mountain Area faults
Whitney Canyon
Woodruff

SUMMARY
THIRD MEETING
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Wednesday & Thursday, December 1 & 2, 2010
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 third WGUEP meeting to order at 8:00 a.m. After welcoming remarks, introductions of WGUEP members (attachment 1), and a review of the meeting's two-day agenda (attachment 2), Bill turned the meeting over to Ivan Wong (WGUEP Chairperson). Ivan recapped the WGUEP process and progress to date, noted some agenda changes (chiefly in the order of the presentations), and then moved the meeting directly to technical presentations and issue discussions.

TECHNICAL PRESENTATIONS

Following Ivan's presentation, the remainder of Wednesday (December 1) and Thursday (December 2) were chiefly devoted to technical presentations and discussions relevant to the WGUEP process. Available Power Point presentations may be viewed at http://geology.utah.gov/ghp/workgroups/wguep.htm.

Wednesday, December 1

- Revised earthquake timing and recurrence models for the central Wasatch fault – Chris DuRoss & Paleoseismology Subgroup
- Strawman rupture models for the central Wasatch fault – Chris DuRoss & Paleoseismology Subgroup
- The Wasatch fault end segments – Geologic and paleoseismic constraints on displacement, slip rate, and recurrence (Malad City, Clarkston Mountain, Collinston, Levan, and Fayette segments) – Mike Hylland
- Update on Utah Geological Survey fault trenching of the Salt Lake City segment (Penrose site) – Chris DuRoss
- Update on fault trenching at the Baileys Lake site, West Valley fault zone – Mike Hylland
- Time-dependent earthquake recurrence models – Nico Luco

Thursday, December 2

- Geodetic data analysis – Mark Petersen
- GPS studies on the Wasatch fault – Bob Smith

- Moment rate for Utah – Mark Petersen
- Estimating maximum (characteristic) magnitudes for faults – Susan Olig
- Should the WGUEP compute time-dependent probabilities for large earthquakes on the East Great Salt Lake fault? – Jim Pechmann
- Update and path forward (TBD) — Background earthquakes in the Wasatch Front area (strawman perspective) – Walter Arabasz
- Other faults in the Wasatch Front area on the bubble – Bill Lund (not a Power Point presentation)
- Other faults in the Wasatch Front region that should be time dependent? – Bill Lund (insufficient time remained for this presentation, postponed until meeting #4)

ISSUE DISCUSSIONS

Note that Power Point presentations and the ensuing discussions that they generated are summarized here. If a presentation was chiefly for information purposes only and no significant discussion followed they were not included in this section (see above for a list of all technical presentations).

Revised Earthquake Timing and Recurrence Models for the Central Wasatch Fault

Chris DuRoss summarized the Paleoseismology Subgroup's final earthquake timing results and uncertainties for the five central Wasatch fault segments, which are based on a product-probability density function (PDF) method for refining segment PDFs. At the subgroup's request, Glenn Biasi, Nevada Seismological Laboratory, reviewed the product method and concluded that it is a reasonable, literature-supported approach (~ maximum likelihood estimation method)—especially for broadly constrained PDFs. Glenn cautioned not to over constrain events, so the subgroup reviewed all site PDFs and final segment PDFs, paying close attention to those that could be considered over constrained, and revised their results accordingly.

The subgroup calculated average segment recurrence intervals for the five central Wasatch fault segments using three techniques:

1. Closed intervals – elapsed time between the oldest and youngest well-constrained events divided by the number of closed intervals.
2. Open interval – elapsed time between oldest event and 2010 (but not open interval prior to oldest event) divided by the number of earthquakes.
3. Mean of the individual earthquake recurrence intervals (e.g., E4-E3, E3-E2, E2-E1).

Comments/discussion following Chris' presentation included:

- The need to carefully justify the use of closed earthquake intervals to calculate recurrence because the UCERF3 working group is presently taking a different approach.

- The Working Group should consider the 'open interval' alternative for use with a Monte Carlo simulation. The open interval is considered the preferred method for determining an earthquake rate for use with a Poisson model.

- The need to address (write up) the evidence for the rate of older (pre-Holocene) earthquakes on the central Wasatch fault (likely slower than the Holocene rate) and describe why the Working Group chose not to use the older record. A recommendation was made to add a low-weight branch to the logic tree to include a slower, long-term slip rate to demonstrate that the Working Group considered it.

- Coefficient of variation (COV) of 0.5 $\pm$ 0.2 has been used for most other earthquake probability studies. Susan Olig stated that a COV of 0.5 may be too high for the Wasatch fault. Dave Schwartz recommended calculating a Wasatch-specific COV for the five central Wasatch fault segments.

- Mark Petersen recommended applying weights on earthquake timing; for example, the timing of E5 on the Brigham City segment is much more uncertain than the timing of E1 through E4. Nico Luco stated that the uncertainty in the mean time interval is not generally used in calculating earthquake probabilities.

- The patterns of individual earthquakes on the central Wasatch fault segments show a high level of aperiodicity. Does this reflect earthquake clustering (Mark) or just statistical variation masked by a short earthquake record (Jim Pechmann)? Nico commented that implementing a cluster model would make calculating time dependence more complicated than the data for the Wasatch fault currently support.

- The timing of older Holocene earthquakes on the Nephi segment remains uncertain – there has been at least one earthquake between 3 and 6 ka, and likely more, but the exact number is unknown, so our knowledge of the mid- to late-Holocene earthquake history is incomplete.

Strawman Rupture Models for the Central Wasatch Fault

The Paleoseismology Subgroup presented three strawman rupture scenarios for the Working Group's consideration:

- Maximum – identifies the maximum number of possible ruptures; includes single-segment ruptures and one leaky-boundary rupture, but no partial segment ruptures.

- Minimum – identifies the fewest number of possible ruptures; includes the maximum number of two-segment ruptures reasonably permitted by earthquake-timing data and segment PDF overlap.

- Preferred – yields mostly single-segment ruptures, but includes "preferred" multi-segment ruptures that have the strongest supporting geologic evidence (timing data, displacements, rupture lengths).

After review of the final Wasatch fault earthquake chronology (figure 1) and considerable discussion among the Working Group members, a preliminary six scenario rupture model (no scenario weights yet assigned) for the past 6.4 ky was agreed upon. The six scenarios are:

1. Maximum earthquake scenario ($\geq$ 22 earthquakes; chiefly single segment ruptures and one partial segment rupture).

2. Minimum earthquake scenario ($\geq$ 13 earthquakes; maximum number of multi-segment ruptures, several only minimally supported by geologic data).

3. Intermediate scenario A (original preferred scenario – includes B4/W5, B3/W4 multi-segment ruptures, and W2/PC1 partial segment rupture; $\geq$ 20 earthquakes).

4. Intermediate scenario B (preferred scenario plus S2/P3 multi-segment rupture; $\geq$ 19 earthquakes).

5. Intermediate scenario C (preferred scenario plus P3/N3 multi-segment rupture; $\geq$ 19 earthquakes).

6. Floating earthquake scenario (move a M 7.4 earthquake along the fault ignoring segment boundaries).

   (B = Brigham City, W = Weber, S = Salt Lake City, P = Provo, N = Nephi)

Additional discussion included:

- How do we model intermediate-magnitude earthquakes (M 6.5 – 6.8) on the Wasatch fault since it is unlikely that geologic evidence for many such events is preserved in the paleoseismic record – use a Gutenberg-Richter model?

- Is M 7.4 an appropriate value for a floating earthquake, or is a magnitude range more appropriate? If so, what is the range and how should it be determined?

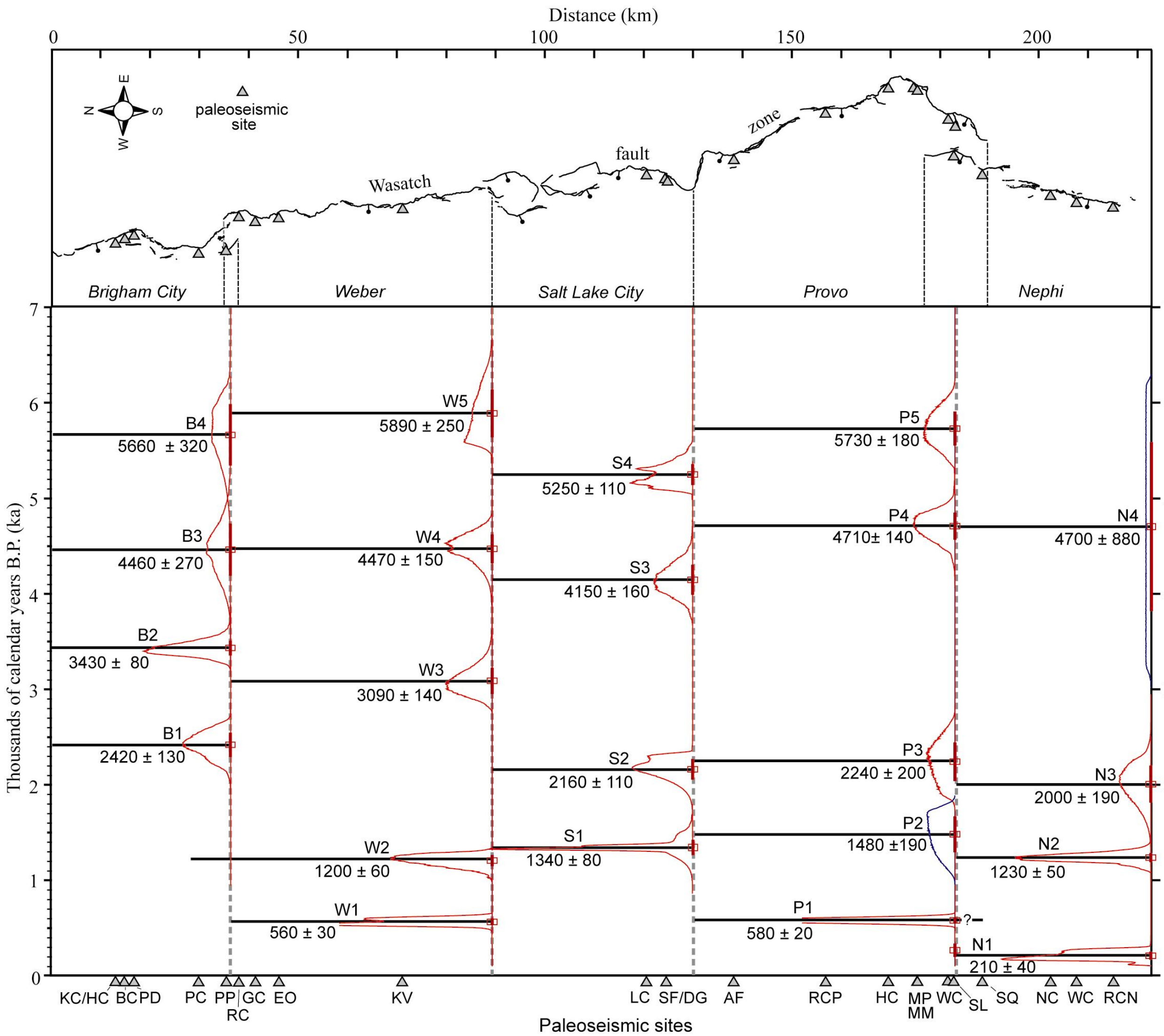


Figure 1. *Final WGUEP earthquake chronology for the five central segments of the Wasatch fault.*

The Wasatch Fault End Segments – Geologic and Paleoseismic Constraints on Displacement, Slip Rate, and Recurrence

Mike Hylland summarized the available slip-rate information for the five Wasatch fault end segments (Malad City, Clarkston Mountain, Collinston, Levan, and Fayette segments – collectively termed the Wasatch fault "end segments").

Trench-derived paleoseismic data are available only for the Levan segment; slip-rate information for the other segments is chiefly based on analyses of fault-displaced geomorphic surfaces. Earthquake timing constraints for the three northernmost segments (Malad City, Clarkston Mountain, and Collinston) are Bonneville lake-cycle (highstand) deposits which are not faulted, so the most recent event (MRE) on these segments is >18 ka. Empirical analysis of scarp profile data from a faulted alluvial fan near the south end of the Clarkston Mountain segment indicate early Holocene surface faulting, but this is likely a minimum age for the MRE; other geologic data suggest active faulting during the late Pleistocene (during or before the end of the Bonneville lake cycle). Limited paleoseismic data for the Levan segment constrain the timing of the MRE to ≤1000 cal yr B.P., and the penultimate event to >2800-4300 cal yr

B.P. and likely >6000-10,600 cal yr B.P. The Utah Quaternary Fault Parameters Working Group (UQFPWG) (Lund, 2005) assigned a consensus slip-rate estimate to the Levan segment of 0.1–0.6 mm/yr. Slip-rate information for the Fayette segment is based on empirical analysis of scarp profile data from fault scarps on early to middle Holocene and late Pleistocene alluvium; however, late Holocene alluvium is not faulted. Slip rates and other earthquake parameters for the Wasatch fault end segments are summarized in table 1.

Table 1. *Wasatch fault end segments summary of earthquake parameters.*

<table>
<tr><th>Segment</th><th>MRE Timing</th><th>Displacement/ Surface Offset (m)</th><th>Time Interval (kyr)</th><th>Estimated Slip Rate (mm/yr)</th><th>Recurrence Interval (kyr)</th></tr>
<tr><td>Malad City</td><td>Late Pleistocene</td><td>≤1.5 (est.)</td><td>>18</td><td><0.08</td><td>NA</td></tr>
<tr><td>Clarkston Mountain</td><td>Late Pleistocene</td><td>2</td><td>>18</td><td><0.1</td><td>NA</td></tr>
<tr><td rowspan="2">Collinston</td><td>Late Pleistocene</td><td>≤2 (est.)</td><td>>18</td><td><0.1</td><td rowspan="2">NA</td></tr>
<tr><td>—</td><td><12</td><td>300</td><td><0.04</td></tr>
<tr><td rowspan="5">Levan</td><td>≤1000 cal yr B.P.</td><td>1.8</td><td>>4.8–9.8</td><td><0.2–0.4</td><td rowspan="5">>3 & <12 (UQFPWG)</td></tr>
<tr><td>1000–1500 cal yr B.P.</td><td>1.8–3.0</td><td>>1.3–3.3</td><td><0.5–2.3</td></tr>
<tr><td colspan="3" rowspan="2"></td><td><0.3±0.1 (H&M, 2008)</td></tr>
<tr><td>0.1–0.6 (UQFPWG)</td></tr>
<tr><td>—</td><td>4.8</td><td>100–250</td><td>0.02–0.05</td></tr>
<tr><td rowspan="3">Fayette</td><td>Early(?) Holocene (SW strand)</td><td>0.8–1.6</td><td><11.5</td><td>>0.07–0.1</td><td rowspan="3">NA</td></tr>
<tr><td>Latest Pleistocene (SE strand)</td><td>0.5–1.3</td><td><18</td><td>>0.03–0.07</td></tr>
<tr><td>—</td><td>3</td><td>100–250</td><td>0.01–0.03</td></tr>
</table>

After review of the end segment slip-rate information, the Working Group decided upon an average slip-rate estimate of 0.01-0.1 mm/yr for the Malad City, Clarkston Mountain, Collinston, and Fayette segments, and adopted the UQFPWG's slip-rate estimate of 0.1–0.6 mm/yr for the Levan segment.

Geodetic Data Analysis

Mark Peterson described recent U.S. Geological Survey (USGS) modeling of Wasatch Front geodetic horizontal extension rate data conducted by himself and Yuehua Zeng. The GPS data were obtained from Puskas and Smith (University of Utah Seismograph Stations). The USGS methodology consisted of:

- Eliminating spurious data.
- Extrapolating to make strain-rate maps.
- Modifying the Puskas and Smith block model (not continuum model, use buried fault model).

- Inverting for slip rate on Wasatch Fault using a block model of elastic upper layer and a creeping lower layer.

The modeling results showed a divergence between the modeled and actual data in some areas of the Wasatch Front, and a strong northwest (strike-slip?) component to the modeled vectors. High extension rates were also noted for some stations on the Colorado Plateau, indicating that the stable continental interior used as the reference against which to compare extension-rate data for the western United States may not be as stable as originally thought.

Additional comments/discussion included:

- The USGS model predicts a high horizontal extension rate on the Levan segment, but geologic slip rates there are low.

- Bob Smith commented that he has noted a shear component in his geodetic data for the southern Provo segment.

- Mark stated that it is time to incorporate GPS data into the USGS National Seismic Hazard Maps (NSHM). Bob commented that the problem is how to partition the horizontal geodetic strain onto individual faults.

- Mark noted that it is also difficult to know how much of the horizontal stain is seismic and how much is aseismic. The USGS currently uses a 50/50 distribution of seismic versus aseismic in the NSHMs.

Moment Rate for Utah

Mark Petersen discussed the USGS methodology used to calculate moment magnitudes for the five central Wasatch fault segments. The USGS assumes (1) lengths based on the current segmentation model, (2) a vertical depth of 15 km for the seismogenic zone, and (3) a range of fault dips from 40-60 degrees. Table 2 shows the segment lengths currently used by the USGS for the Wasatch fault in the NSHMs and the assigned and calculated earthquake magnitudes for the Wasatch fault segments. Some discussion ensued regarding whether or not these are the right segment lengths (straight line versus trace length) for the USGS to be using.

Table 2. *USGS Wasatch fault segment length and magnitude parameters.*

Segment	Length (km)	Assigned Magnitude	Calculated Magnitude
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 showed three east-west profiles (northern Wasatch Front, central Wasatch Front, Wasatch Plateau/Sevier Desert) along which the USGS calculated horizontal slip rates using geologic data available for the major faults crossed by the profiles. The results are generally lower than the horizontal extension rates obtained from GPS measurements in the same areas. Finally, Mark reviewed the characteristic earthquake parameters and the floating earthquake and Gutenberg-Richter parameters used for the Wasatch fault on the NSHMs, and presented a comparison of downdip slip rates calculated for the six central Wasatch fault segments (table 3) using geologic and geodetic data from three different sources.

Table 3. *USGS comparison of downdip slip rates for six central segments of the Wasatch fault.*

Segment	Geologic slip rate (mm/yr +/- 15%)	RI based slip rate (mm/yr +/- 15%)	Geodetic slip rate (Zeng)	Geodetic slip rate (Chang and Smith)	Puskas and Smith
Brigham City	1.83	0.80	2.2	5-12	2-3
Weber	1.57	1.36	2.6	5-12	2-3
Salt Lake City	1.57	0.97	4.1	5-12	2-3
Provo	1.57	1.31	4.3	5-12	2-3
Nephi	1.44	0.55	4.3	5-12	2-3
Levan	0.39	0.22	3.3	5-12	2-3

Discussion included:

- The assumed 15 km vertical depth needs uncertainty limits.
- Calculations using seismic moment give a M 7.4 earthquake on the Wasatch fault every 653 years and a M 7.0 earthquake every 164 years. These values are clearly too short and contradict the paleoseismic data.
- Dave stated that seismic moment should be based on an analysis that includes uncertainties on both length and width.
- Ivan posed this question – are we going to use geodetic data in our time-dependent model, and if so, how?

- Dave stated that we should use geologic rates for individual faults and use geodetic rates as a regional constraint. Dave doesn't think that regional geodetic strain can be directly assigned to the Wasatch fault.

- Bob stated that the geodetic data are robust and contribute to the hazard, and therefore should be incorporated into the model, but he is unsure at this time how to do it. It will be hard for the Working Group to justify not using observed data that bears directly on the problem.

- Jim Pechmann advocated taking a close look at existing block models (dip, depth, slip rate), and thinks that the result would show that geologic slip rates and geodetic extension rates are close to the same.

- Susan agreed with Dave that there is too much uncertainty related to partitioning geodetic extension rates on individual faults. Additionally, Susan agreed with Jim that through time geodetic and geologic rates seem to be getting closer together, and that a thorough comparison of the latest geologic and geodetic data that also documents modeling uncertainties is needed before the Working Group can use geodetic data in the forecast model.

- Mark indicated that the USGS will use geodetic data on the next update of the NSHMs, based on the geodetic community's strong opinion/recommendation that the data are robust and it is time to incorporate them into the maps.

- Tony Crone agreed that we need to incorporate geodetic into our time-dependent model on a regional basis, but he is unsure how to do it.

- Mark advocated convening a workshop for geodetic modelers to figure out what are the next steps necessary to incorporate geodetic extension data in the NSHMs and time-dependent fault models.

- Ivan agreed with Mark, but noted that the long time frame required to organize the workshop and obtain results, makes it unlikely that the results will be available for the WGUEP effort.

- Walter Arabasz suggested making a careful comparison of GPS-derived seismic moment rates with the seismic moment release rate calculated from historical (earthquake catalog) and paleoearthquakes (paleoseismic data). He recommended subdividing the WGUEP study area into three subregions for purposes of the comparison (Northern Utah-Idaho, Wasatch Front corridor, and the West Desert).

- Jim supported Walter's suggestion, but advocated doing a regional comparison rather than using subregions.

- Bob agreed that making such a comparison might allow us to determine what percentage of the observed geodetic rate is seismic related, and stated that he will think about how to approach such a project.

Estimating Maximum (Characteristic) Magnitudes for Faults

Susan Olig reviewed the empirical relations (variously based on fault area, length, displacement [average and maximum], slip rate [average], and seismic moment) currently used to estimate maximum moment magnitudes for faults. Based on her review, she recommended that the Working Group use the following relations for calculating M_{max}:

- Wells and Coppersmith (1994) – all fault types
  - – Surface rupture length (L); M = 5.08 + (1.16 x log L)
  - – Average and maximum slip (AD & MD); M = 6.93 + (0.82 log AD); M = 6.69 + (0.74 x log MD)

- 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 (AD x MVCDS)

- Leonard (2010) – interplate dip-slip faults
  - Area (A); M = log A + 4.0

Susan presented a strawman approach for calculating M_{max} for the faults in the WGUEP study area as follows.

1. Categorize faults according to available data.
   A. Well-mapped with 3 or more trench sites
   B. Well-mapped with 1 or 2 trench sites (some D data)
   C. Mapped and no trench sites (no D data)

2. Use different empirical relations (and uncertainties) based upon available data and segmentation models.
   - For category A faults use:
     - Wells and Coppersmith – L (all fault types)
     - Hemphill-Haley and Weldon – AD
     - Leonard – A (for interplate-related dip slip)
   - For category B faults use:
     - Wells and Coppersmith – L (all fault types)
     - Wells and Coppersmith – AD (all fault types)
     - Wells and Coppersmith – MD (all fault types)
     - Leonard – A (for interplate-related dip slip)
   - For category C faults use:
     - Wells and Coppersmith – L (all fault types)
     - Leonard – A (for interplate dip slip)

Report the average weighted-mean of the magnitude values, and use ± 0.3 M for 5th and 95th percentiles (our model will include various rupture scenarios, which address some epistemic uncertainty; this also assumes some aleatory uncertainty will be included in forecast calculations – how much should be added ± 0.25 M?)

Discussion included:

- Dave's preference is to use Hanks and Kanamori (1979 [Seismic moment (M_O); M = (2/3 x log M_O) – 10.7]) where the data permit. He has concerns about using individual parameter regressions, particularly displacement parameters, because we often (usually) don't know what those parameters really are, and the result can be highly uncertain estimates of magnitude.

- Dave noted that equating maximum and characteristic with regard to earthquake magnitudes is probably something we don't want to do.

- Concern was expressed by some Working Group members that automatically including $\pm$ 0.3 M for epistemic uncertainty and possibly $\pm$ 0.25 M for aleatory uncertainty would result in unrealistically large M_{max} upper bound estimates. Susan agreed that using sigma for the empirical relations is an option, care must be taken because in some cases uncertainties can get so large they result in unrealistically large values of M_{max} ($\geq$ M 7.8).

Should the WGUEP Compute Time-Dependent Probabilities for Large Earthquakes on the East Great Salt Lake Fault?

Jim Pechmann summarized the paleoseismic data presently available for the East Great Salt Lake Fault (see tables 4 and 5).

Table 4. *Earthquake timing for the East Great Salt Lake fault.*

Earthquake	^{14}C yr BP (before 1950)	Calendar yr BP (before 1950); Stuiver et al., 1998 terrestrial calibration	Residence-corrected calendar years BP (before 1950)	Residence-corrected calendar years before 2007
Antelope Island segment				
EH-A3	> 804 ± 38 < 1027 ± 44	> 706 $^{+81/-40}$ < 944 $^{+106/-147}$	586 $^{+201/-241}$	643 $^{+201/-241}$
EH-A2	5711 ± 50	6491 $^{+163/-135}$	6170 $^{+236/-234}$	6227 $^{+236/-234}$
EH-A1	9068 ± 66	10,219 $^{+178/-234}$	9898 $^{+247/-302}$	9955 $^{+247/-302}$
Fremont Island segment				
EH-F3	3269 ± 47	3471 $^{+161/-90}$	3150 $^{+235/-211}$	3207 $^{+235/-211}$
EH-F2	5924 ± 44	6733 $^{+121/-90}$	6412 $^{+209/-211}$	6469 $^{+209/-211}$
EH-F1	<10,155 ± 72	<11,748 $^{+580/-406}$	<11,427 $^{+605/-449}$	<11,484 $^{+605/-449}$

Jim concluded that the earthquake timing data for the Antelope Island and Fremont Island segments of the East Great Salt Lake fault are reliable and that whether a time-dependent analysis of the fault is possible or not depends on if the Working Group thinks two average recurrence intervals are sufficient data for the analysis.

Table 5. *Earthquake recurrence intervals for the East Great Salt Lake fault.*

Earthquake pairs	**Dates of occurrence (residence-corrected cal yr before 1950)**	**Recurrence interval (yr)**
Antelope Island segment (M_{max} = 6.9)		
EH-A3 **EH-A2**	$596^{+201/-241}$ $6170^{+236/-234}$	$5584^{+219/-172}$
EH-A2 **EH-A1**	$6170^{+236/-234}$ $9898^{+247/-302}$	$3728^{+223/-285}$
Fremont Island segment (M_{max} = 6.6-6.7)		
EH-F3 **EH-F2**	$3150^{+235/-211}$ $6412^{+209/-211}$	$3262^{+151/-184}$
EH-F2 **EH-F1**	$6412^{+209/-211}$ $< 11{,}427^{+605/-449}$	$< 5015^{+587/-424}$

Average single-segment recurrence interval = 4200 ± 1400 years

Discussion included:

- The earthquake timing data are compelling; the Working Group should compare the results of time-dependent and time-independent analyses of the fault.

- Ivan requested that Jim prepare strawman rupture scenarios for our next meeting.

Update and Path Forward (TBD) — Background Earthquakes in the Wasatch Front Area

Walter Arabasz summarized the current status of the analysis of background seismicity in the WGUEP study area:

1. Decision made after the last WGUEP meeting to await the end of this year to have an earthquake catalog complete through 2010.

2. The steps needed to do the analysis rigorously are apparent in state-of-practice PSHAs.

3. Because this will be a USGS-endorsed product, the analysis ideally should be based on a "consensus" catalog developed collaboratively with the USGS (efforts being undertaken elsewhere to unify hazard information in the U.S.).

Walter showed an example of USGS Web-based earthquake probability mapping, to make the point that the WGUEP products will have competitors, and that coordination with the USGS is important. He then summarized the process required to achieve a consensus catalog and presented the following steps as a reasonable path forward:

1. Need to decide/agree on scope and rigor of steps for analysis,

2. At least make an attempt to move in the direction of a consensus catalog with USGS,

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

4. Complete steps and analysis.

Other Faults in the Wasatch Front Area on the Bubble

At the July WGUEP meeting, the Working Group eliminated 55 of the 122 Quaternary faults or fault segments in the WGUEP study area (table 6) from further consideration in the WGUEP earthquake forecast process. The WGUEP identified an additional 10 faults or fault segments (tables 6 and 7) whose activity levels were questionable, and recommended additional review to determine if they should be retained in the WGUEP active fault inventory. At this WGUEP meeting, Bill Lund summarized available paleoseismic information for these ten "bubble" faults/segments. Based on that review, the Working Group retained the East Cache fault zone northern section, and the Stinking Springs fault in the active fault database. The Joes Valley fault zone east faults, west faults, and intergraben faults; the Ogden Valley North Fork fault; Ogden Valley SW Margin faults; Long Ridge Northwest side fault; Long Ridge West side fault; and the Sublette Flat fault were removed from further consideration in the WGUEP process (table 7). The decision to remove the Joes Valley faults was based upon a recent investigation by the U.S. Bureau of Reclamation that determined those faults likely do not penetrate to seismogenic depths. The remaining faults removed from the database all had low slip rates (<0.2 mm/yr) and times of most recent deformation of Middle and late Quaternary (<750 ka) or Quaternary (<1.6 Ma).

Table 6. *Summary of actions taken regarding Quaternary faults in the WGUEP Wasatch Front Study Region active fault database at the second WGUEP meeting in July 2010.*

Parameters	Remaining Faults	Deleted Faults	Questionable Faults
Total	57	55	10
<0.2 mm/yr	38	55	8
> 0.2 mm/yr < 1.0 mm/yr	11	–	2
> 1.0 mm/yr < 5.0 mm/yr	6[1]	–	–
Unknown	2	–	–
Historical	1	–	–
Latest Quaternary < 15 ka	40	4	3[2]
Late Quaternary < 130 ka	11	4	1
Middle Quaternary < 750 ka	4	20	3
Quaternary < 1.6 Ma	–	27	3
Unknown	1	–	–
< 5 km	3	20	–
5 – 10 km	4	8	1
10 – 15 km	5	10	1
15 – 20 km	11	5	1
20 – 25 km	8	2	1
25 – 30 km	6	3	1
30 – 35 km	6	1	1
35 – 40 km	2	3	1
> 40 km	12	3	3

[1]Includes the five Wasatch fault segments with multiple Holocene earthquakes
[2]Includes the three Joes Valley fault zone segments

Table 7. *Dispositions of "bubble" faults at the third WGUEP meeting in December, 2010.*

Fault/Segment	Slip Rate Category	Length	Time of Most Recent Deformation	Disposition
ECFZ Northern section	<0.2 mm/yr	41	Quaternary (<1.6 Ma)	Retained
Stinking Springs fault	<0.2 mm/yr	10	Late Quaternary (<130 ka)	Retained
Joes Valley fault zone east fault	Between 0.2 and 1.0 mm/yr	57	Latest Quaternary (<15 ka)	Deleted
Joes Valley fault zone intergraben faults	<0.2 mm/yr	34	Latest Quaternary (<15 ka)	Deleted
Joes Valley fault zone west faults	Between 0.2 and 1.0 mm/yr	84	Latest Quaternary (<15 ka)	Deleted
Long Ridge Northwest side	<0.2 mm/yr	21	Quaternary (<1.6 Ma)	Deleted
Long Ridge West side fault	<0.2 mm/yr	15	Middle and late Quaternary (<750 ka)	Deleted
Ogden Valley North Fork fault	<0.2 mm/yr	26	Middle and late Quaternary (<750 ka)	Deleted
Ogden Valley SW Margin faults	<0.2 mm/yr	18	Middle and late Quaternary (<750 ka)	Deleted
Sublette Flat	<0.2 mm/yr	36	Quaternary (<1.6 Ma)	Deleted

TASK LIST

The following tasks were either assigned at the third WGUEP meeting or are unresolved tasks remaining from previous meetings:

9. Explore different approaches to calculate earthquake recurrence (appropriate time-dependent models for the Wasatch fault) – Ivan and Nico.

10. Compare horizontal extensional strain rates with geologic (vertical) slip-rate data for the Wasatch Front study region (What is the best way to convert horizontal geodetic extension rates to fault dip-slip rates?) – Mark and Bob.

11. Calculate a revised COV for the Wasatch fault using the updated WFZ earthquake chronology developed by the paleoseismology data subgroup – Susan and others.

12. Determine the best approach(s) for calculating M_{max} (length, displacement, area) for study area faults – Dave and Susan.

13. Develop a methodology for moment balancing normal faults (create moment-balance model for the Wasatch fault) – Mark plus USGS group.

14. Develop a "consensus" Wasatch Front earthquake catalog complete through 2010 – Walter and Jim.

15. Complete megatrench report and distribute to other Working Group members – Susan.

16. Develop strawman rupture scenarios for the East Great Salt Lake fault – Jim.

17. Review which, if any, remaining other faults in the WGUEP study region should be time dependent – Bill.

18. Develop strawman logic tree and target products – Ivan.

NEXT MEETING

The next WGUEP meeting is scheduled for February 16 & 17, 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, UGS*
Bill Lund, UGS, Coordinator*
Susan Olig, URS Corporation*
James Pechmann, UUSS*
Steve Personius, USGS*
Mark Petersen, USGS*
Dave Schwartz, USGS*
Bob Smith, UUGG*
Ivan Wong, URS Corporation, Chair*
Steve Bowman, UGS Liaison to WGUEP*

*Attended meeting 3

ATTACHMENT 2
AGENDA
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Wednesday/Thursday, December 1 & 2, 2010
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

1 December 2010

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome	Bill
8:15 – 8:30	Overview of Agenda	Ivan
8:30 – 10:00	Report from Paleoseismology Subgroup – Revised Earthquake Timing, Recurrence, and Strawman Rupture Scenarios for Central Wasatch Fault	Chris
10:00 – 10:15	Break	Chris
10:15 – 12:00	Discussion of Rupture Scenarios and Final Model Selection and Weighting	Chris
12:00 – 1:00	Lunch	
1:00 – 1:30	Final Slip Rates for Wasatch Fault End Segments	Mike
1:30 – 2:00	Update on Salt Lake City Fault Trenches	Chris
2:00 – 2:45	Update on West Valley Fault Zone Trenches	Mike
2:45 – 3:00	Break	
3:00 – 4:00	Earthquake Recurrence Models	Ivan/Nico
4:00 – 5:00	General Discussion	Ivan

2 December 2010

7:30 – 8:00	Continental Breakfast	
8:00 – 9:00	Conversion of Horizontal Geodetic Extension Rates to Fault Dip-Slip Rates	Mark
9:00 – 9:30	Mmax Calculations	Susan
9:30 – 10:30	Moment Balancing	Mark
10:30 – 10:45	Break	
10:45 – 11:30	Time-Dependent Recurrence for Great Salt Lake Fault?	Jim
11:30 – 12:00	Other Faults that Should be Time-Dependent?	Bill
12:00 – 1:00	Lunch	
1:00 – 1:30	Other Faults on the Bubble	Bill
1:30 – 2:00	Update on Wasatch Front Background Earthquakes	Jim/Walter
2:00 – 3:00	Discussion and Path Forward	Ivan
3:00	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

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

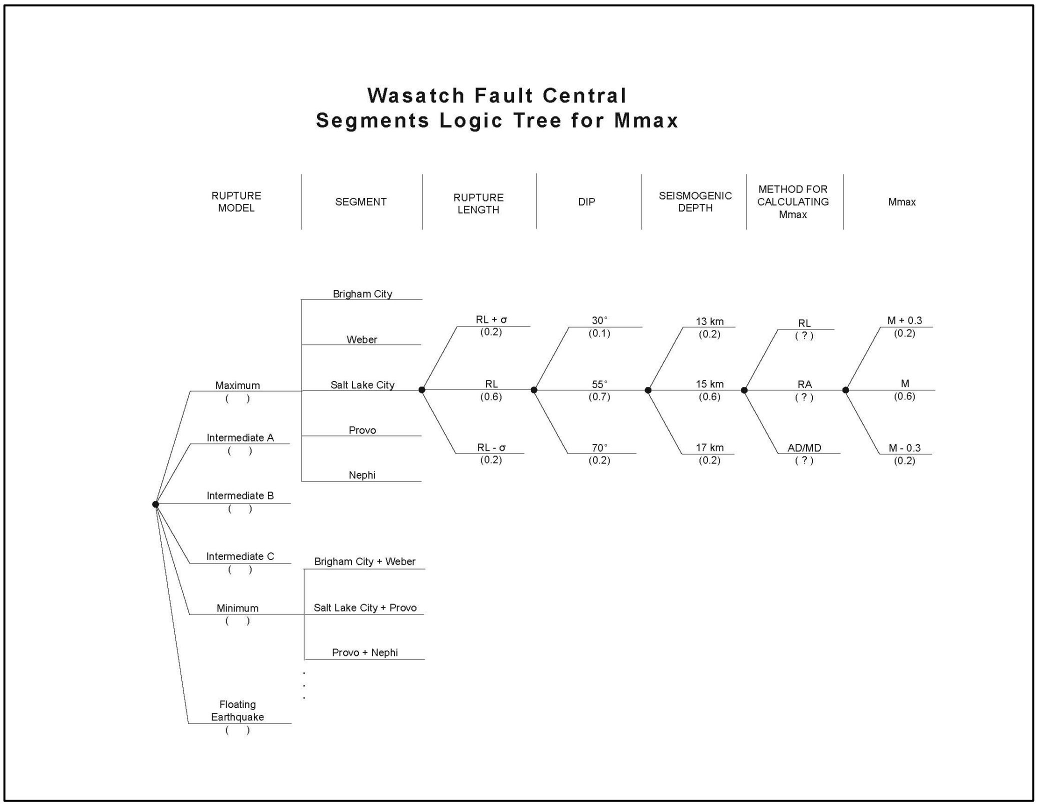
Strawman Logic Tree

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$\pm$10 degrees (40-50-60) for the dip of basin-and-range-style normal faults on the National Seismic Hazard Maps (NSHMs). The Working Group recommended trying both 30-55-70 and 50$\pm$10 degrees to see how much difference changing the dip makes to the WGUEP probability calculations. (Note that on the second day of the meeting, the Working Group recommended using 50$\pm$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.



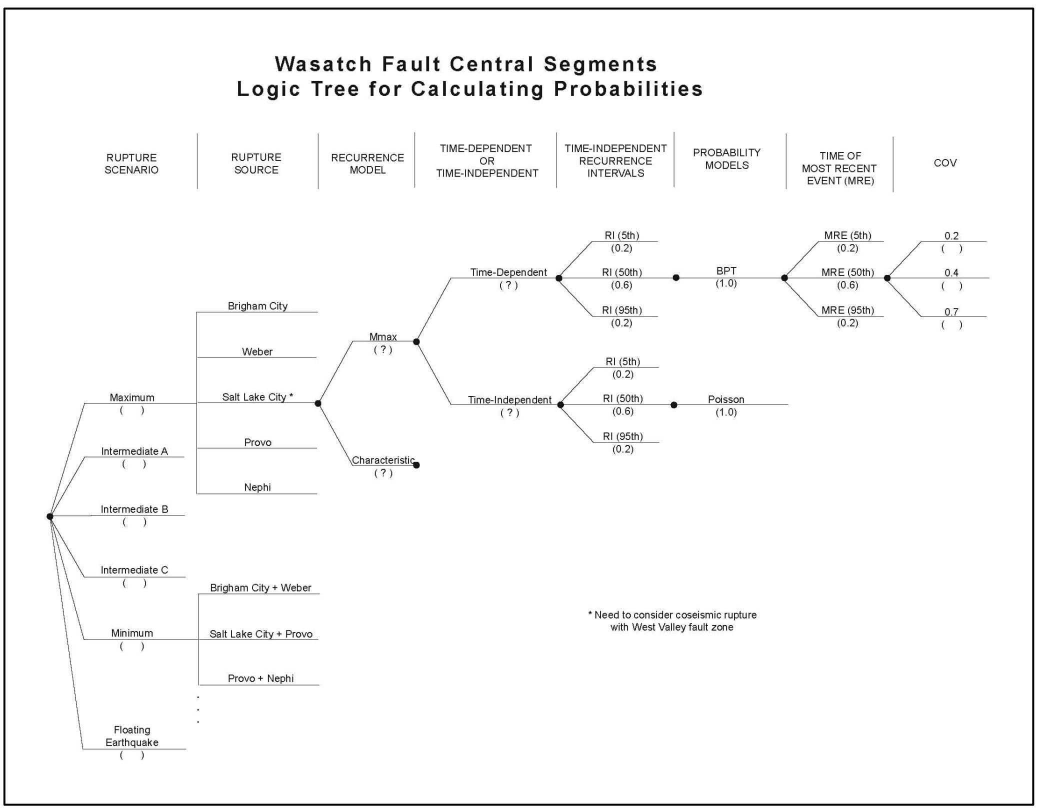


Figure 1. Strawman logic trees (A) for calculating M_{max} and (B) for calculating probabilities.

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 ± 1 σ 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 ± 1 σ):
  - Wells and Coppersmith – L (0.5)
  - Wells and Coppersmith – A (0.5)

- Truncate all distributions at M 7.8 maximum. Use aleatory uncertainty of ± 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•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.

<table>
<tr><th colspan="4">Rupture Scenarios</th><th>WS1</th><th>WS2</th><th>WGUEP</th></tr>
<tr><td>R</td><td>P</td><td>FI</td><td>AI</td><td>0.75</td><td>0.68</td><td>0.75</td></tr>
<tr><td colspan="2">R+P</td><td>FI</td><td>AI</td><td>0.05</td><td>0.08</td><td>0.00</td></tr>
<tr><td>R</td><td colspan="2">P+FI</td><td>AI</td><td>0.00</td><td>0.00</td><td>0.00</td></tr>
<tr><td>R</td><td>P</td><td colspan="2">FI+AI</td><td>0.05</td><td>0.08</td><td>0.10</td></tr>
<tr><td colspan="2">R+P</td><td colspan="2">FI+AI</td><td>0.05</td><td>0.08</td><td>0.00</td></tr>
<tr><td colspan="4">Unsegmented</td><td>0.10</td><td>0.08</td><td>0.15</td></tr>
</table>

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$\pm$10 degrees for the NSHMs as recommended by the BRPEWG (2005). After considerable discussion, the Working Group came to consensus on 50$\pm$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

16 February 2011

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	

17 February 2011

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	

WGUEP Members

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

Other Participants

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

SUMMARY
FIFTH MEETING
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Tuesday & Wednesday, June 28 & 29, 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 fifth WGUEP meeting to order at 8:00 a.m. After welcoming the Working Group members, other topic presenters, and visitors (attachment 1), Bill turned the meeting over to Ivan Wong (WGUEP Chairperson) who reviewed the meeting agenda (attachment 2) and recapped WGUEP progress to date.

WGUEP TASK LIST REVIEW

Ivan then reviewed the current WGUEP task list and revisited other issues related to the WGUEP process to ensure that the Working Group had achieved consensus on those topics.

Current Task List

1. Recurrence Model Subgroup (Ivan, Walter, and Jim) to develop a set of strawman recurrence model weights for the Working Group's consideration. (*Delayed until after the Basin and Range Province Earthquake Working Group II [BRPEWGII] meeting in November.)*

2. Validate comparison of geodetic, historical earthquake, and geologic moment rates and provide a recommendation of how to incorporate GPS horizontal extension data in the WGUEP probability forecast. (*Christine Puskas (Robert Smith proxy) has accepted a job outside Utah and is no longer available to perform this function. Jim Pechmann has agreed to perform this task with Mark Petersen, and is working with Christine to resolve some issues with her previous comparison. Dave Schwartz recommended making a comparison of vertical and horizontal geologic rates with geodetic rates at all points across the Wasatch fault zone [WFZ] where data are available and displaying the results on a map.)*

3. Weight WFZ rupture scenarios, sum moment release per segment per scenario, and compute and plot magnitude frequency distributions for rupture scenarios. (*Presentation by the Paleoseismology Subgroup to follow on this topic.)*

4. Evaluate software for running a Brownian Passage Time probability model/evaluate other probability models. *(Have obtained the software used for California Working Group 2002 (WG02) – a presentation by Patricia Thomas will follow on this topic.)*

5. Revise historical earthquake catalog – Seismology Subgroup (Walter, Ivan, Jim, and Mark). *(A presentation by Walter Arabasz and Jim Pechmann will follow on this topic.)*

6. Decide on final WGUEP products (full model building or simplified product; Ivan and Mark). *(A presentation by Ivan Wong will follow on this topic.)*

7. Recompute vertical slip rates and M_{max}, and devise a reliability indicator for the paleoseismic data in the WGUEP "Other Fault" database. *(A presentation by Bill Lund will follow on this topic.)*

8. Determine what to use as the maximum magnitude background earthquake (M 6.75±, M 6.6 ± 0.2, other?); Ivan, Mark). *(This topic will receive further discussion at this meeting.)*

Other Issues

1. Range of fault dips. *(This topic was discussed at WGUEP meeting #4 [see meeting #4 summary at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011A_Summary.pdf]. The Working Group decided at that time to use 50±15 degrees as the dip for all faults in the "Other Fault" database for the WGUEP study area. A decision regarding the range of dips to use for the WFZ was not finalized at meeting #4. The working group's consensus at meeting #5 was to use 50±15 degrees for all range-bounding faults in the WGUEP study area.)*

2. Range of seismogenic depths. *(This topic was also discussed at WGUEP meeting #4. The Working Group decided at that time to use a range of 15±2 kilometers as the seismogenic depth for faults in the WGUEP study area. That decision was confirmed at meeting #5.)*

3. Northern three (Malad, Clarkston Mountain, Collinston) and southern two (Levan and Fayette) WFZ segments – model them separately or combine them and float an earthquake along their combined length? *(Given the uncertainties regarding both slip rate and surface rupture length for these segments, the Working Group is considering modeling both scenarios and weighting them 50/50, but a final decision is still pending.)*

4. Unsegmented rupture model. *(Working Group members agreed that the unsegmented rupture model for the central WFZ should be allowed to include the end segments. Working Group members also discussed magnitude distributions for earthquakes in the unsegmented model. The consensus was to use a maximum magnitude of 7.5 considering the WFZ M_{max} data (discussed below) and the Hebgen Lake earthquake; however, the Working Group considered minimum magnitudes between 6.5 and 6.8. The Working Group did not reach consensus regarding minimum M.)*

TECHNICAL PRESENTATIONS

The meeting then moved into a series of technical presentations and issue updates. PowerPoint presentations made at the meeting are available at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Presentations.pdf.

Tuesday, June 28

- WGUEP Products and Issue of Consistency with USGS Maps – Ivan Wong
- BRPEWGII Workshop Issues – Tony Crone
- Update on Recurrence Models – Ivan Wong
- Update on Final Wasatch Central Segment Recurrence Rates and COVs – Chris DuRoss

Wednesday, June 29

- Update on West Valley Fault Zone and Coseismic Rupture – Mike Hylland
- Update on "Other" Faults – Bill Lund
- Path Forward on Use of Geodetic Data – Jim Pechmann
- Inputs for Forecast and Moment Balancing – Patricia Thomas
- Update on Consensus Wasatch Front Earthquake Catalog – Walter Arabasz/Jim Pechmann
- Spatial Smoothing Versus Uniform Source Zone(s) – Ivan Wong
- M_{max} for Background Earthquakes – Ivan Wong

ISSUE DISCUSSIONS

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

WGUEP Products

- Segment-specific time-dependent and time-independent probabilities of the characteristic earthquake on the five central segments of the WFZ. (Note that time-dependent probabilities may be calculated with some weight given to a time-independent approach.)
- Time-dependent and time-independent probabilities for the whole WFZ for $\geq$M 6.5 and $\geq$M 7.0 and events.
- Segment-specific and fault-specific time-dependent and time-independent probabilities for the Great Salt Lake fault zone.
- Time-independent probabilities for each of the "Other" faults in the Wasatch Front.
- Time-dependent and time-independent probabilities for the Wasatch Front study area for a range of magnitudes starting at M $\geq$ 5.0.
- Time-independent probability for background earthquakes in the Wasatch Front study area for a range of magnitudes starting at M $\geq$ 5.0.
- Map of time-dependent probabilities for the Wasatch Front study area.

Basin and Range Province Earthquake Working Group II Issues

The Basin and Range Province Earthquake Working Group II (BRPEWGII) is patterned after BRPEWGI (http://ugspub.nr.utah.gov/publications/open_file_reports/OFR-477.pdf, convened in Salt Lake City in 2006. In a manner similar to BRPEWGI, the objective of BRPEWGII is to provide recommendations to the U.S. Geological Survey's (USGS) Seismic Hazard Mapping Project on Basin and Range Province (BRP) related topics important to the 2013 update of the National Seismic Hazard Maps (NSHMs). The Working Group will meet in Salt Lake City on Nov. 14–16, 2011, and will include participants from federal and state government agencies, academia, and private industry. The USGS, Western States Seismic Policy Council, and Utah Geological Survey are providing support for BRPEWGII. Discussions will focus on (1) seismological topics, and (2) topics related to the geological evaluation of seismic sources. Geodetic issues will be discussed in a separate NSHM national workshop.

Topic I: Seismology

S1. How should the magnitude-frequency relations for a single Basin and Range Province (BRP) fault be characterized? Does existing seismological data help define this relationship?

S2. How should the "smoothing" of seismicity be handled in the National Seismic Hazard Maps (NSHMs)? The current NSHMs use a radial smoothing process, but recent precarious rock studies in California and western Nevada suggest that anisotropic smoothing (i.e., along faults) might be more appropriate? If anisotropic smoothing is used, should it be applied universally across the entire BRP?

S3. Does the rate of earthquakes represented on the NSHMs need to match the rate of historical earthquakes? If not, what level of mismatch is acceptable?

S4. What are the sources and levels of uncertainty in the earthquake magnitudes contained in the seismicity catalogs used in the NSHMs?

Topic II: Geologic Evaluation of Seismic Sources

G1. How should we calculate M_{max} for BRP faults based on rupture lengths, fault areas, and available displacement data (M_{max} of 7.5 currently is used in the NSHMs and is based on the magnitude of the 1959 Hebgen Lake earthquake)? What is the source or explanation of the discrepancy between M calculated using surface-rupture length versus using the average or maximum displacement (site bias, underestimation of surface rupture length, other)? How should the discrepancy in the magnitude determined from these two measurements be handled in the NSHMs?

G2. How should antithetic fault pairs be modeled in the NSHMs? For example, what is the relation and seismogenic significance of fault pairs such as the East and West Cache faults, and strands of the Salt Lake City segment of the Wasatch fault and the West Valley fault zone?

G3. The USGS seeks guidance on how to estimate the uncertainty for the slip rates on BRP normal-slip faults, especially for faults that have little or no slip-rate data. The method used in California to estimate the uncertainty has varied the upper and lower bounds of the slip rate by plus-or-minus 50%. Thus, the uncertainty bounds for a fault that has a slip rate of 5 mm/yr would be 7.5 mm/yr and 2.5 mm/yr. Do these bounding values encompass the fifth and ninety-fifth percentiles for this fault?

G4. Based on the recommendations from BRPEWGI, the current USGS NSHMs use a dip of 50°±10° for normal faults in the BRP. Are the 50° dip value and the ±10° uncertainty range valid and acceptable to cover the probable range of dips for BRP normal faults?

Many of the issues selected for consideration at BRPEWGII are similar to those considered at BRPEWGI. Answers to these questions aren't simple or clear. Refining input into the NSHMs is an iterative process; the goal is to assure that each update includes improved data and information, which yields a better representation of seismic hazard at a national level.

Update on Recurrence Models

The Working Group must decide which earthquake recurrence model(s) to use for the WGUEP process. Ivan reviewed the three recurrence models and their typical assigned weights traditionally used by the consulting industry when performing probabilistic seismic hazard analyses (PSHAs): M_{max} (0.3), Characteristic (0.6), and Truncated Exponential (0.1). Ivan noted that based on work being conducted by Abrahamson and Hecker he expects that the truncated exponential model will soon be given no weight.

Ivan then reviewed the set of two recurrence models used by the USGS for the NSHMs, which differs from the set of models typically used by the consulting industry for PSHAs. The USGS refers to one of their models as a "Characteristic" model; however, it differs in significant ways from the traditional characteristic model of Youngs and Coppersmith and is more commonly called the "Maximum Magnitude" (M_{max}) model. The USGS NSHMs use both the M_{max} and a "Gutenberg-Richter" (truncated exponential) model for faults, with weights of 2/3 and 1/3, respectively, for faults in the Intermountain West region. The USGS Gutenberg-Richter model is for M 6.5 and greater earthquakes only. This approach came about because of the mismatch of predicted and observed rates of moderate magnitude earthquakes in southern California. The USGS model places no moderate sized ($M < 6.5$) earthquakes on faults unless M_{max} for the fault is less than 6.5. Smaller events are accommodated by a background zone with a relatively large M_{max} of 7.0 (reduced near modeled faults).

A key question for the Working Group is should we adopt the traditional approach to recurrence models or use the USGS model? Implications of the model(s) selected include (1) do we think, or do we want the outside community to think, that the WFZ follows a truncated exponential model, and (2) do moderate magnitude earthquakes occur on or near faults at a greater rate than elsewhere? Ivan noted that the California Working Groups used the USGS model because background seismicity in California is a big player in the near term.

Further discussion on this topic was deferred to WGUEP Meeting #6 in November, 2011.

Update on Final Wasatch Central Segment Recurrence Rates and COVs

Chris DuRoss presented the results of the Paleoseismology Subgroup's effort to (1) weight the segment rupture scenarios for the five central segments of the WFZ and for the West Valley fault zone (WVFZ), (2) sum the moment release per segment per scenario, (3) plot magnitude frequency distributions for the rupture scenarios, and (4) calculate coefficients of variation (COV) for the WFZ segments and the fault as a whole. See Chris' PowerPoint presentation at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Presentations.pdf for supporting details:

(1) The Paleoseismology Subgroup's recommended WFZ rupture scenario weights as follows:

- Maximum rupture model (22 earthquakes) 50%
- Minimum rupture model (14 earthquakes) 5%
- Intermediate rupture model A (19 earthquakes) 10%
- Intermediate rupture model B (19 earthquakes) 10%
- Intermediate rupture model C (20 earthquakes) 15%
- Unsegmented earthquake model 10%

The recommended rupture scenario weights for the WVFZ and the adjacent Salt Lake City segment (SLCS) of the WFZ are as follows:

- WVFZ ruptures independently 50%
- WVFZ ruptures coseismically with SLCS (adds M_0) 45%
- WVFZ is non-seismogenic 5%

SLCS scenarios

- SLCS ruptures without WVFZ (SLCS only contributes M_0) 55%
- SLCS ruptures coseismically with WVFZ (both contribute M_0) 45%

(2) The Paleoseismology Subgroup used two seismic moment (M_0) calculations: (1) M_0 = rigidity (μ) * area (A; down-dip rupture length * surface rupture length [SRL]) * average net displacement (D) (Hanks and Kanamori, 1979), and (2) Log M_0 = 3/2 [M_W (based on SRL)] + 16.05 (Hanks and Kanamori, 1979).

- Displacement conclusions
    - D was calculated using a simple method (average of observed displacements per rupture) and an analytical method following Chang and Smith (2002) and Biasi and Weldon (2009) (half-ellipse displacement profile). For the WFZ, the analytical half ellipse was scaled using the observed displacements rather than an SRL-D regression (see Biasi and Weldon, 2009).
    - The subgroup reported very similar results in using the simple versus analytical methods of calculating D. However, the WFZ per-event displacements are consistently large (average of 2.8 m in each rupture model), bringing into question site bias (small displacements under-sampled) and/or underestimated SRLs. These large displacements contribute to significant discrepancies in M_W and M_0 when based on D versus SRL or area.

- M_0 conclusions
    - Using M_0 (μAD), the five rupture scenarios have similar amounts of moment release (summed per segment and for the WFZ). Consistent results were obtained using both the observed and modeled average displacements. Because of the available WFZ displacement data, it is not likely that M_0 (μAD) underestimates moment release for larger ruptures (displacements are not significantly larger in multi-segment ruptures, and we're probably not missing the largest displacements). However, it is possible that M_0 (μAD) overestimates M_0 for smaller (single-segment) ruptures (longer SRLs than mapped, site bias?).
    - M_0 (μAD) consistently yields more moment release (per earthquake, segment, and rupture model) than M_0 based M_W(SRL). Given the large WFZ displacements, M_0(μAD) better portrays moment release than M_0(SRL) (more M_0 released in single- and multi-segment ruptures than indicated by M_0(SRL) regression)

(3) The Paleoseismology Subgroup calculated M_W using the following regressions:

- M_W
    - M_W (SRL) = 1.16* LOG(SRL)+5.08 (W&C94–all-fault-types); range based on SRL uncertainty
    - M_W (A) = 4.07+0.98*LOG(DDW*SRL) (W&C94–all-fault-types); range based on DDW and SRL uncertainties
    - M_W (AD–HH&W99) (in progress…)

        - M_W (AD–W&C94): M_W (AD[net]) = 0.82*(LOG(AD[net]))+6.93 (all-fault-types)
        - M_W (M_0) = (2/3)*(LOG(M_0)) - 10.7 (H&K79)

- Mean M_W
    - M_W (SRL) – 0.25 wt
    - M_W (A) – 0.25 wt
    - M_W (AD–W&C94) – 0.25 wt
    - M_W (M_0) – 0.25 wt

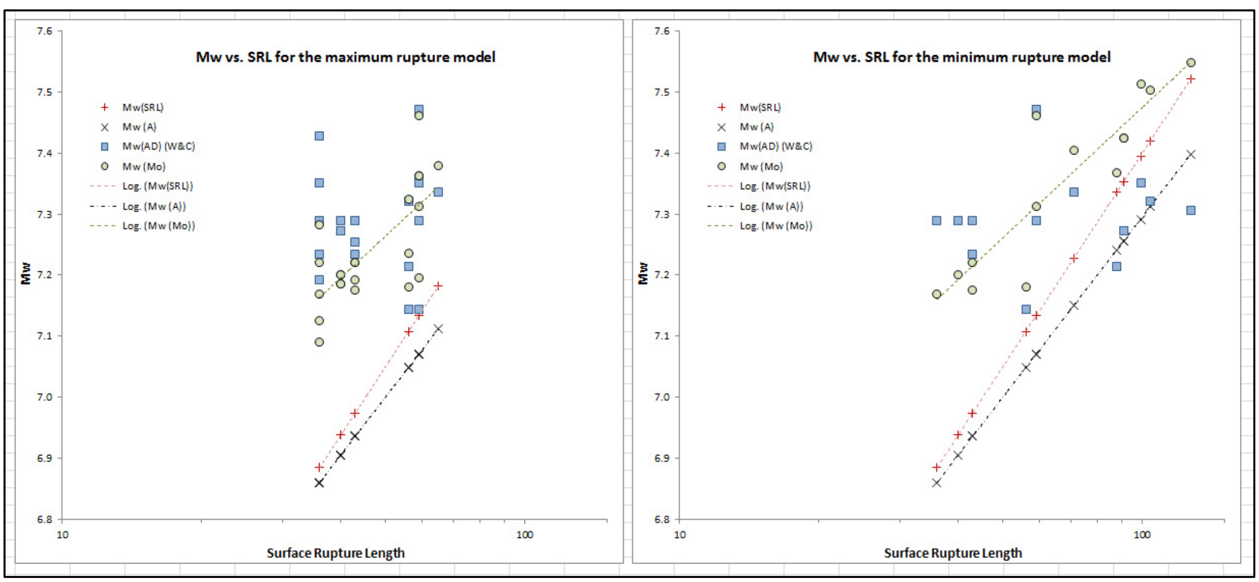
Moment Magnitude

- Maximum model
    - M_W (SRL): <u>7.0 ± 0.2</u>
    - (6.9 ± 0.2 – 7.1 ± 0.2)
    - M_W (A): <u>7.0 ± 0.2</u>
    - (6.7 ± 0.2 – 7.2 ± 0.2)
    - M_W (AD): 7.3 ± 0.2
    - M_W (M_0-mAD): 7.2 ± 0.2
    - Mean M_W: 7.1 ± 0.2

- Minimum model
    - M_W (SRL): <u>7.2 ± 0.4</u>
    - M_W (A): <u>7.1 ± 0.3</u>
    - M_W (AD): 7.3 ± 0.1
    - M_W (M_0-mAD): 7.4 ± 0.3
    - Mean M_W: 7.2 ± 0.3

M_w vs. SRL

- The subgroup reported significant discrepancies in M_W when based on D versus SRL or area.



<u>Maximum model</u>
M_W (D or M_0) consistently greater than M_W (SRL or A)

<u>Minimum model</u>
M_W (D or M_0) generally greater than M_W (SRL or A)

M_W Frequency

- M_W frequencies reported were based on the number of occurrences of earthquakes of a particular SRL divided by the total elapsed time (7.1-ka max constraint for W5 to present). For example, in the max model a 43-km-SRL earthquake occurs 4 times in 7.1 years. See Chris' PowerPoint presentation at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Presentations.pdf for the M_w-frequency plots.

- The Working Group discussed the displacement data and apparent discrepancy between M_0 and M_W when based on µAD and M_W(SRL). Note that this topic will receive further discussion at the BRPEWGII meeting.

(4) COV

1. Determine earthquake times per segment (one out of 10,000 scenarios). Using the Brigham City model, simulation1 has the following earthquake times:
   - E4: 5615
   - E3: 4355
   - E2: 3500
   - E1: 2225
2. Compute recurrence intervals (RIs):
   - E4-E3: 1260
   - E3-E2: 855
   - E2-E1: 1275
3. Calculate COV = standard deviation of RIs (238 yr) divided by their mean (1130 yr):
   - COV = 238/1130 = 0.21
4. Repeat, and then compile and plot earthquake times, RIs, and COVs

COV results per segment:

- Brigham City 0.3 ± 0.4 (2s)
- Weber and Salt Lake City 0.5 ± 0.3 (WS) 0.5 ± 0.2 (SLCS)
- Provo 0.6 ± 0.3
- Nephi 0.7 ± 0.5 (E4-E1), 0.2 ± 0.4 (E3-E1)

Considerable discussion followed regarding the correct procedure for calculating COVs for each rupture model and for the WFZ as a whole. Mark suggested following the lead of the California Working Groups and adopting a COV of 0.5±0.2. The consensus of the Working Group was to attempt to calculate a single composite COV for the WFZ. Chris indicated that he would consult with Jim and Nico on the best way to make the calculations.

Update on West Valley Fault Zone and Coseismic Rupture

Mike Hylland reviewed the most recent results from the WVFZ Baileys Lake paleoseismic trenching study, and the resulting implications for weighting WVFZ rupture activity. The numerical age data available at this time allow OxCal modeling of only the most recent paleoearthquake. The results of OSL analyses (in progress) are needed before the timing of the earlier earthquakes can be modeled.

Preliminary Results

Baileys Lake site shows evidence of at least four large earthquakes.

Earthquake timing:

- P4 – Warping event around the time of the Bonneville highstand (~18 ka)
- P3 – Surface faulting during lake regression from the Provo shoreline, possibly during the period of very low lake level prior to the Gilbert transgression (~12 ka)
- P2 – Surface faulting sometime after the Gilbert lake cycle (early Holocene)
- P1 – Surface faulting during the mid-Holocene (5.6 ± 0.8 ka)

Vertical displacement:

- Average per-event vertical displacement ~0.5 m

Modeled timing of P1 is in very good agreement with timing of SLCS event E2 at the Penrose Drive site.

Current thoughts on weighting WVFZ activity (WGUEP Paleoseismology Subgroup):

- 0.50 independent (currently 0.25 in the NSHMs)
- 0.45 dependent (coseismic with SLCS, adds moment to SLCS earthquake)
- 0.05 non-seismogenic (space-accommodation structure)

Mike discussed three historical earthquakes that may provide analogs for WVFZ fault activity as it relates to the SLCS of the WFZ. The three earthquakes were Devils Canyon, Idaho (M 5.8 and an antithetic M 5.0 aftershock; 1984), Irpinia, Italy (M 6.9; 1980), and Hansel Valley, Utah (M 6.6; 1934). Summary information for each of these earthquakes is contained in Mike's PowerPoint presentation at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Presentations.pdf.

Update on "Other" Faults

Bill Lund provided an update (no PowerPoint) on the effort to recompute vertical slip rates and M_{max} using available paleoseismic data for the "Other" faults in the WGUEP study area. Bill stated that he is well underway with the project, and has consistently used 50±15 degrees for fault dips and 15±2 kilometers for seismogenic depth in his calculations. Bill noted that well documented displacement data are rare for the "Other" faults, and consequently he has a low level of confidence in most M_{max} values determined using displacement data. In nearly every instance where displacement data are available, it is unknown if the data represent average or maximum values, and it is most likely that they represent neither. Dave Schwartz suggested that the WGUEP follow the California Working Groups' practice of using only M_{max} values determined using SRL or Area. This elicited considerable discussion, since values of M_{max} determined using SRL and Area are consistently lower than M_{max} values obtained from displacement data.

Chris DuRoss recommended that "Other" faults with a minimum of three displacement observations from three independent sites be treated as type A faults in the ranking system devised by Susan Olig and Dave Schwartz for calculating M_{max} (see discussion in WGUEP Meeting #4 summary at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011A_Presentations.pdf). In all other cases, he recommended treating the "Other" faults as type C faults and using SRL and Area to calculate M_{max}. The Working Group seemed to concur with this suggestion. Bill will continue to calculate M_{max} using SRL, Area, and displacement where available, and will devise a system to rank the quality of the displacement data and the reliability of the M_{max} values obtained from them. However, given the quantity and quality of the displacement data, most displacement-based M_{max} values for the "Other" faults should be considered poorly constrained estimates at best.

Bill stated that based on comments made by Lucy Piety, U.S. Bureau of Reclamation (USBR), at the 2011 Utah Quaternary Fault Parameters Working Group meeting in February, he recommends restoring the Joes Valley faults to the WGUEP “Other Fault” database. The USBR is not yet convinced that the Joes Valley faults are nonseismogenic, and they intend to conduct additional studies of those faults in the future.

Path Forward on Use of Geodetic Data

Jim Pechmann reviewed Christine Puskas’ comparison of geodetic, historical earthquake, and geologic moment rates across the Wasatch Front (see WGUEP Meeting #4 Summary at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011A_Presentations.pdf). Jim noted that Christine’s comparison showed that geodetic moment was generally an order of magnitude greater than geologic moment. Based on similar comparisons that Jim and others have done in the past, Jim was concerned that the difference was too high. A close review of Christine’s calculations showed that she had used an incorrect rigidity constant ($3x10^{11}$ PA = $3x10^{12}$ dynes/cm^2 instead of $3x10^{11}$ dynes/cm^2) for her calculations, which resulted in the order of magnitude discrepancy. Jim also noted that the three boxes (north, central, south) spanning the Wasatch Front within which Christine computed geologic moment did not correspond with WFZ segment boundaries, making calculation of the geologic moment released within the boxes difficult. Additionally, the boxes are large and contain other active faults that may contribute geologic moment not included in Christine’s calculations. Jim attempted to reproduce Christine’s calculations of geologic moment rates using Kostrov’s equation, the Wells and Coppersmith (1994) M(SRL) relation, and paleoearthquake models for the five central segments of the Wasatch fault only (following Christine). Jim counted only the moment release rates from the sections of the Wasatch fault within Christine’s boxes, which is necessary when applying Kostrov’s equation to the crustal volumes represented by these boxes. Jim’s calculated geologic moment rates were on average 2.6 times lower than those that Christine reported. (Based on correspondence with Christine following the meeting, Jim identified two errors in the methodology that Christine used to determine her geologic moment rates.)

Based on his review, Jim concluded that for Christine’s northern and central boxes, geodetic moment is a factor of two to three times (depending on the rupture model used) greater than geologic moment. For the southern box, geodetic moment is a factor of five to ten times greater than geologic moment. The reasons for these discrepancies remain unclear, but may be due in part to missed contributions to geologic moment rates from faults not included in the analysis.

In the ensuing discussion regarding how to incorporate the geodetic data in the WGUEP process, it was noted that the geodetic data could provide an estimate of extension in a volume of crust across a region (Wasatch Front), and therefore provide a check on geologic rates. Areas with large discrepancies could be targeted for additional study to resolve significant differences. However, the geodetic data alone is not sufficient to enable geodetic extension to be partitioned among individual faults. Walter stated that the Geodetic Data Subgroup should write a commentary on the utility/application of geodetic data to the WGUEP process to diffuse possible reviewer criticism.

Discussion ensued regarding a path forward that involved using a block model and/or Kostrov’s equation (which are essentially equivalent) to calculate average strain or extension rates for the entire WGUEP Wasatch Front block. Mark Petersen indicated that he could average the GPS strain rate across the Wasatch Front and compare it to the geologic strain rate to look for discrepancies between the two. Ivan stated that he would send the geologic model to Mark so he could calculate geologic moment rates.

Inputs for Forecast and Moment Balancing

Patricia Thomas reported that URS Corporation has acquired the computer code used for California WG02, and that she plans to follow a procedure similar to WG02 for WGUEP. Patricia discussed the steps required to implement the WG02 code: See Patricia’s PowerPoint presentation at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Presentations.pdf for supporting details:

1. Define fault segment attributes
2. Define rupture sources and rates
3. Define background seismicity
4. Define probability model parameters
5. Probability calculations

And summarized the various inputs required for the model:

1. Geometry
   - Segment endpoints
   - Seismogenic thickness
   - Dip
2. Long term segment slip rate?
3. Regional moment rate constraint?
4. Mean characteristic magnitude models
5. Average displacement for rupture sources
6. Magnitude probability density models
7. Fault rupture models (rupture sources, scenarios, weights)
8. Background seismicity parameters
9. Probability models and weights
10. Probability model parameters
    - Time since last event, COV

Update on Consensus Wasatch Front Earthquake Catalog

Walter Arabasz and Jim Pechmann updated the Working Group on efforts to compile a consensus Wasatch Front earthquake catalog.

Collaboration with the USGS:

- Discussions started with Chuck Mueller in January 2011.

- Working Group teleconference (Wong, Arabasz, Pechmann, Mueller, Petersen) on May 17, 2011.

- USGS/NSHM catalog through 2010 for "extended Utah region" (36.0°−43.5° N, 108°−115° W) delivered by Chuck Mueller to Arabasz and Pechmann on June 6, 2011.

Walter compared the University of Utah Seismograph Stations (UUSS) and National Seismic Hazard Maps (NSHM) earthquake catalogs for the WGUEP region and noted the discrepancy between the two catalogs in the number of independent main shocks (declustered using different methods) in the $4.0 \leq M < 4.5$ and $5.0 \leq M < 5.5$ bins.

Magnitude Range	UUSS Catalog	NSHM Catalog
$4.0 \leq M < 4.5$	45	34
$4.5 \leq M < 5.0$	5	4
$5.0 \leq M < 5.5$	10	21
$5.5 \leq M < 6.0$	4	4
$6.0 \leq M < 6.5$	3	3
$6.5 \leq M < 7.0$	1	1
Total Number	68	67

Comparison of UUSS and NSHM catalogs for the WGUEP region (1880 through 2010; independent main shocks $M \geq 4.0$, non-tectonic events removed).

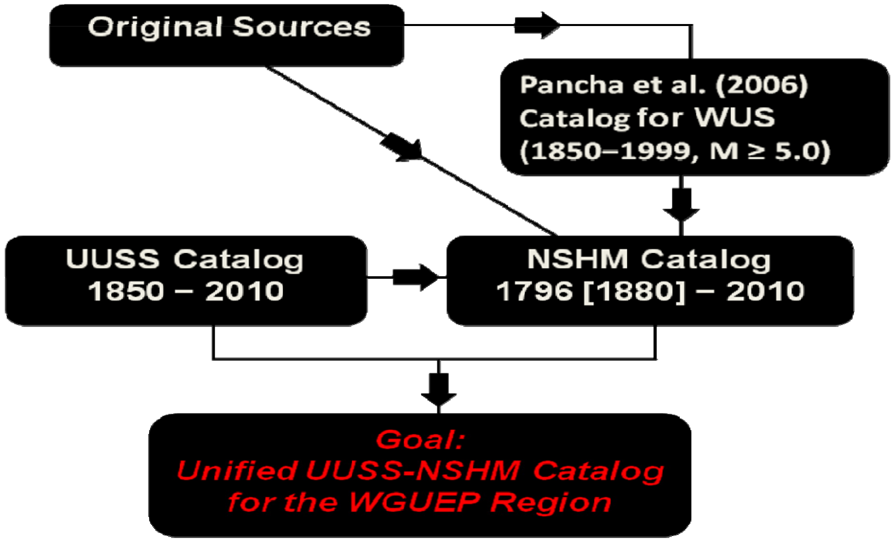
After accounting for time- and magnitude-dependent variations in catalog completeness, a similar discrepancy between the two catalogs was noted in the number of $4.67 \leq M < 5.33$ independent main shocks.

Magnitude Range	Completeness Period	Years	UUSS Catalog	NSHM Catalog
$4.00 \leq M < 4.67$	July 1962−Dec 2010	48.5	17	16
$4.67 \leq M < 5.33$	Jan 1950−Dec 2010	61.0	7	17
$5.33 \leq M < 6.00$	Jan 1938−Dec 2010	73.0	1	1
$6.00 \leq M < 6.67$	Jan 1900−Dec 2010	111.0	3	3

Comparison of independent main shocks ($M \geq 4.0$) in the UUSS and NSHM catalogs for the WGUEP Region — accounting for completeness periods.

The latter discrepancy between the two catalogs is likely due to the importation of events into the NSHM catalog from the Pancha and others (2006) catalog for the western United States (1850−1999) for $M \geq 4.8$.

Walter presented the following diagram outlining the path forward to achieving a unified UUSS–NSHM earthquake catalog, and noted the effort required to create such a catalog represents a nontrivial task in terms of time and effort. Walter hopes that with some help, a consensus catalog can be complete by the end of the year.



Spatial Smoothing Versus Uniform Source Zone(s)

This discussion centered on whether the WGUEP wants to include a uniform background zone, in additional to Gaussian smoothing to account for non-stationarity in the historical record. That is, should we allow for the possibility that background earthquakes in the Wasatch Front region could occur in locations that have not occurred in the historical record. Both approaches could be weighted as was done for the Salt Lake Valley microzonation maps that were developed by Wong and others. The USGS uses uniform background zones in the western U.S. to provide a hazard floor in areas of low seismicity. No decision was made. A less significant issue is what kernel size to use in the smoothing. The USGS uses 50 km in most of the western U.S., including Utah, in contrast to the Salt Lake Valley microzonation maps where 15 km was used. An adaptive kernel approach could also be used in which this issue would be addressed.

M_{max} for Background Earthquakes

The discussion centered on what M_{max} should be considered for the background earthquake. Previous studies in the Wasatch Front have generally used M 6.5 +/- 0.25. The USGS uses a M_{max} of M 7.0 which seems too high. The answer to the question depends on the minimum M_{max} for faults that would be observed at the surface after repeated events. The prevailing thinking was that M 6.5 was too low. Hence, Ivan suggested a preliminary M_{max} of M 6.75 +/- 0.25. Further discussion is needed here.

TASK LIST

1. Recurrence Model Subgroup (Ivan, Walter, and Jim) develop a set of strawman recurrence models and weights for the Working Group's consideration. This will be done after the BRPEWGII. Also determine the M_{max} distribution for background earthquakes.

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 (Jim and Mark).

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

4. Calculate COV for WFZ segments and the fault as a whole (Chris, Nico, Jim).

5. Recompute vertical slip rates and M_{max}, and devise a reliability indicator for the displacement data in the WGUEP "Other" faults database (Bill).

6. Address Gaussian smoothing versus uniform background zone (Ivan, Mark).

7. Make trial probability calculation by November meeting (Ivan and Patricia).

Additionally, a number of issues need to be addressed regarding implementing the WGCEP code (Patricia, Susan, Ivan).

REFERENCES

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

NEXT MEETING

The next WGUEP meeting is scheduled for November 16–18, 2011, at 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 (participated via phone)
Bill Lund, UGS, Coordinator
Susan Olig, URS Corporation
James Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
Dave Schwartz, USGS
Bob Smith, UUGG*
Ivan Wong, URS Corporation, Chair
*Absent

Others presenting or assisting the Working Group

Steve Bowman, UGS Liaison to WGUEP
Mike Hylland, UGS
Patricia Thomas, URS Corporation

AGENDA

WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #5
Tuesday & Wednesday, 28 & 29 June 2011
Utah Department of Natural Resources Building, Room 2000 (2^{nd} floor)
1594 West North Temple, Salt Lake City

<u>28 June 2011</u>

7:30 – 8:00	Continental Breakfast	
8:00 – 8:15	Welcome	Bill
8:15 – 8:30	Overview of Agenda	Ivan
8:30 – 9:00	WGUEP Products and Issue of Consistency with USGS Maps	Ivan
9:00 – 10:00	BRPEWG Workshop Issues	Mark/Tony
10:00 – 10:15	Break	
10:15 – 10:45	Update on Recurrence Models	Ivan
10:45 – 11:45	Update on Final Wasatch Central Segment Recurrence Rates and COVs	Chris
11:45 – 12:45	Lunch	
12:45 – 1:45	Inputs for Forecast and Moment Balancing	Patricia
1:45 – 2:15	Update on West Valley Fault Zone and Coseismic Rupture	Mike
2:15 – 2:45	Update on Other Faults	Bill
2:45 – 3:00	Break	
3:00 – 4:30	Path Forward on Use of Geodetic Data	Mark/Ivan
4:30 – 5:00	Wrap-up Discussion	All

<u>29 June 2011</u>

7:30 – 8:00	Continental Breakfast	
8:00 – 8:30	Update on Consensus Wasatch Front Earthquake Catalog	Walt/Jim
8:30 – 9:15	Spatial Smoothing Versus Uniform Source Zone(s)	Ivan
9:15 – 10:00	M_{max} for Background Earthquakes	Ivan
10:00 – 10:15	Break	
10:15 – 12:00	Open Discussion	
12:00 – 12:30	Lunch	
12:30 – 3:00	Open Discussion and Schedule	
3:00	Adjourn	

<u>WGUEP Members</u>

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

<u>Other Participants</u>

Patricia Thomas, URS
Steve Bowman, UGS
Mike Hylland, UGS

SUMMARY
SIXTH MEETING
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Thursday & Friday, November 17 & 18, 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 sixth WGUEP meeting to order at 8:30 a.m. After welcoming the Working Group members and UGS staff (attachment 1), Bill turned the meeting over to Ivan Wong (WGUEP Chairperson) who reviewed the meeting agenda (attachment 2) and recapped WGUEP progress to date.

TECHNICAL PRESENTATIONS

The meeting then moved into a series of technical presentations and issue updates. PowerPoint presentations made at the meeting are available at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011C_Presentations.pdf.

Thursday, November 17

- Update on Consensus Wasatch Front Earthquake Catalog – Walter Arabasz
- Strawman Recurrence Models – Ivan Wong
- Data Needs for Probability Calculations and Input Sensitivities – Patricia Thomas
- WGUEP: Wasatch Fault Zone Recurrence Rates and COVs – Chris DuRoss (two PowerPo
- Update on "Other Faults" Database – Bill Lund (no PowerPoint)
- Update on calculating M and M_o for the Wasatch Fault Zone – Susan Olig/ Chris DuRoss

Friday, November 18

- Path Forward on Use of Geodetic Data – Ivan Wong (no PowerPoint)
- Spatial Smoothing Issues – Mark Petersen (no PowerPoint)
- M_{max} for Background Earthquakes – Ivan Wong (no PowerPoint)
- Modeling Graben-Bounding Faults in the NSHMs – Mike Hylland (two PowerPoints)
- Dip Angles for Basin and Range Normal Faults – Tony Crone

- Oquirrh-Great Salt Lake Fault Zone – Susan Olig/Jim Pechmann

ISSUE DISCUSSIONS

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

Update on a Consensus Wasatch Front Earthquake Catalog

Walter Arabasz updated the WGUEP on his effort to compile a consensus Wasatch Front earthquake catalog. The principal points of Walter's presentation included:

- Methodology preview: magnitude uncertainties and rate calculations from seismicity.

- University of Utah Seismograph Stations (UUSS) magnitudes (historical – $M_{L\,(Io)}$; instrumental – M_L, M_C, and M_w).

- More on the comparison between UUSS and National Seismic Hazard Maps (NSHM) catalogs (and magnitudes).

- Next steps to closure.

Why Magnitude Uncertainties are Important

- Recurrence calculations for rigorous hazard and risk analyses require an adjustment for magnitude uncertainties because they introduce bias (*a*-values are systematically overestimated).

- Bias arises because errors in magnitude estimates are normally distributed while earthquake counts in magnitude bins are exponentially distributed.

- Magnitude uncertainties come from: (1) statistical average of measurements made at a number of stations, and (2) conversion from one magnitude scale to another; errors also occur from rounding.

Methodology Status

- Standard errors for magnitude estimates in the UUSS catalog can be provided for $M_{L\,(Io)}$, M_L, and M_C, and rounding values can be provided.

- Have to decide on approach to uniform magnitude (M_W) — Event-by-event conversion to M_W? Assume M_L and M_C sufficiently equivalent to M_W?

- Size estimates for pre-instrumental shocks ($M_{L\,(Io)}$) have relatively large uncertainty; intensity-magnitude relation will be examined with added data, and sizes of larger events re-examined.

- Assumption is that WGUEP earthquake catalog will be turned over to URS Corporation/U.S. Geological Survey (USGS) "analysts" for bias-corrected rate calculations and probabilities.

Walter then discussed and compared the UUSS and NSHM earthquake catalogs for the WGUEP region, and noted the discrepancy between the two catalogs in the number of independent main shocks (declustered using different methods) in the $4.0 \leq \mathbf{M} < 4.5$ and $5.0 \leq \mathbf{M} < 5.5$ bins (table 1).

Table 1. *Comparison of UUSS and NSHM catalogs for the WGUEP region (1880 through 2010; independent main shocks **M** ≥ 4.0, non-tectonic events removed).*

Magnitude Range	UUSS Catalog	NSHM Catalog
$4.0 \leq \mathbf{M} < 4.5$	45	34
$4.5 \leq \mathbf{M} < 5.0$	5	4
$5.0 \leq \mathbf{M} < 5.5$	10	21
$5.5 \leq \mathbf{M} < 6.0$	4	4
$6.0 \leq \mathbf{M} < 6.5$	3	3
$6.5 \leq \mathbf{M} < 7.0$	1	1
Total Number	68	67

After accounting for time- and magnitude-dependent variations in catalog completeness, a similar discrepancy between the two catalogs was noted in the number of $4.67 \leq \mathbf{M} < 5.33$ independent main shocks (table 2). The latter discrepancy between the two catalogs is likely due to the importation of events into the NSHM catalog from the Pancha and others (2006) catalog for the western United States (1850−1999) for $\mathbf{M} \geq 4.8$.

Table 2. *Comparison of independent main shocks (**M** ≥ 4.0) in the UUSS and NSHM catalogs for the WGUEP region — accounting for completeness periods.*

Magnitude Range	Completeness Period	Yrs	UUSS Catalog	NSHM Catalog
$4.00 \leq \mathbf{M} < 4.67$	July 1962−Dec 2010	48.5	17	16
$4.67 \leq \mathbf{M} < 5.33$	Jan 1950−Dec 2010	61.0	7	17
$5.33 \leq \mathbf{M} < 6.00$	Jan 1938−Dec 2010	73.0	1	1
$6.00 \leq \mathbf{M} < 6.67$	Jan 1900−Dec 2010	111.0	3	3

Walter again presented figure 1 below, which outlines the path forward to achieve a unified UUSS–NSHM earthquake catalog.

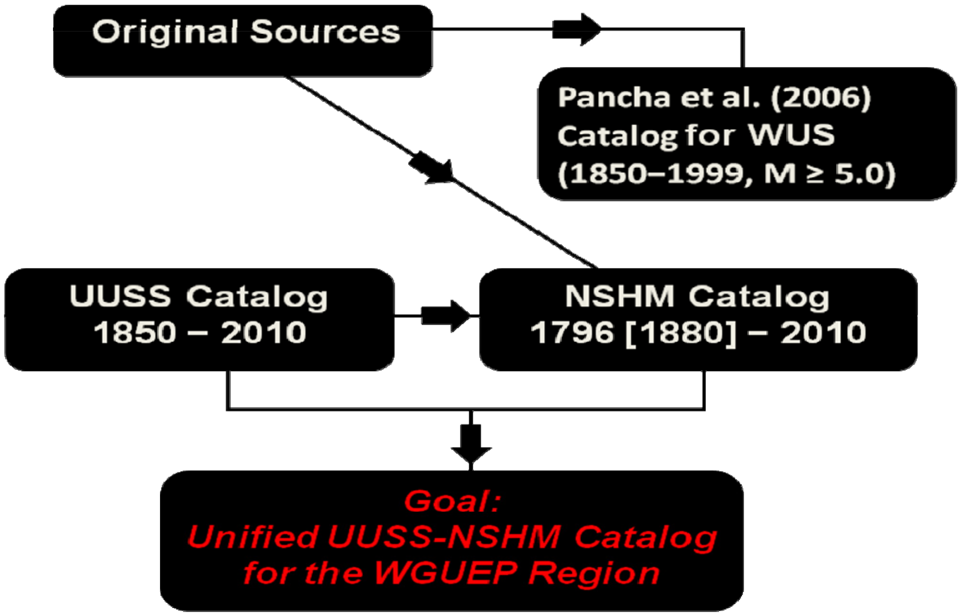


Figure 1. *Path forward to achieve a unified UUSS–NSHM earthquake catalog.*

Next Steps to Closure

Walter presented the remaining six steps required to achieve closure on a consensus UUSS/NSHM earthquake catalog.

1. Identify parts of the WGUEP catalog (a) that will come directly from the UUSS instrumental catalog, and (b) that will represent a unified blending of UUSS and NSHM catalogs.

2. Verify periods of completeness using "Stepp" plots.

3. Revise or confirm the intensity-magnitude relation for pre-instrumental shocks in the Utah region with added data.

4. Decide on an approach to achieve "uniform **M**" in the catalog.

5. Determine values of σ and rounding errors for various magnitude estimates in the WGUEP catalog that will be needed by the analysts for bias corrections.

6. Reconcile differences in magnitudes between the NSHM and UUSS catalogs — based on careful checking of sources, compilation of available size estimates, and assessment of a preferred magnitude — to achieve a unified catalog.

Update on Strawman Recurrence Models

At WGUEP Meeting 5, Ivan Wong reviewed the three recurrence models and their typical assigned weights traditionally used by the consulting industry when performing probabilistic seismic hazard analyses (PSHAs): M_{max} (0.3), characteristic (0.6), and truncated exponential (0.1) (see figure 2 for recurrence model examples). Ivan noted that based on work being conducted by Abrahamson and Hecker, he expects that the truncated exponential model will soon be given no weight.

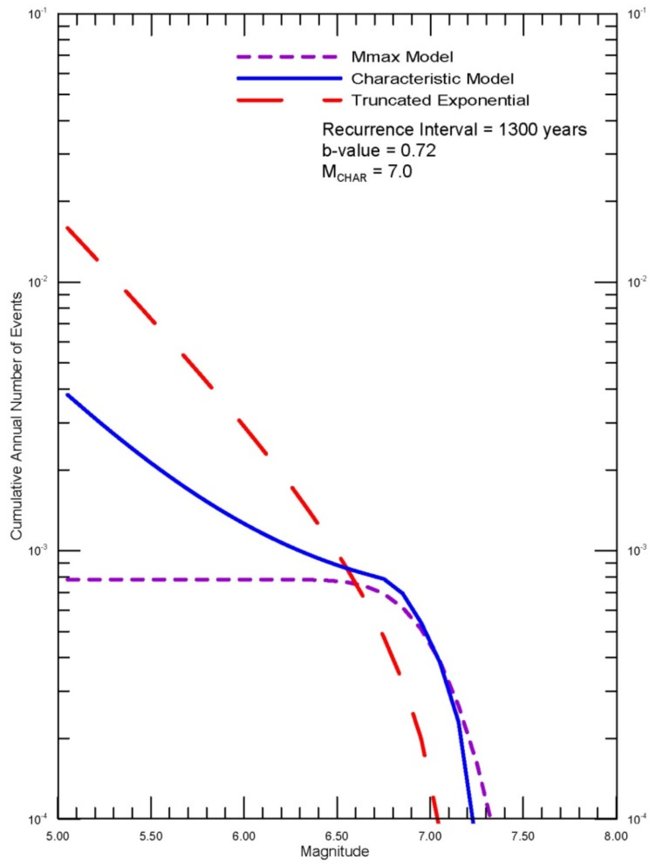


***Figure 2.** Recurrence model examples.*

A decision regarding which recurrence model(s) WGUEP should adopt was deferred at WGUEP Meeting 5 until WGUEP Meeting 6, at which time a "strawman" WGUEP recurrence model would be presented for the Working Group's consideration.

At Meeting 6, Ivan again reviewed the USGS NSHM recurrence model approach:

- Use both "characteristic" (actually maximum magnitude) and Gutenberg-Richter models,
- Both models have their M_{min} at **M** 6.5 for faults,
- M_{min} 6.5 came about because of mismatch of **M** 4-5 earthquakes in southern California,
- Background earthquakes are accommodated by smoothed seismicity. Gutenberg-Richter model has a M_{max} of **M** 6.5, and
- M_{max} for gridded seismicity is lowered over dipping faults to avoid overlap.

Ivan showed a figure presenting various recurrence models for the Salt Lake City segment of the Wasatch fault zone (WFZ) (figure 3). He then presented a table showing expected return periods for ≥ **M** 5, ≥ **M** 6, and ≥ **M** 7 earthquakes for the 100% M_{max}, 100% characteristic, and 50% M_{max} / 50% characteristic models (table 3).

Ivan then presented a “strawman” WGUEP recurrence model developed by the Seismology Subgroup (Ivan, Jim Pechmann, and Walter Arabasz) for the Working Group’s consideration:

- Wasatch fault zone and Oquirrh-Great Salt Lake faults
  0.9 maximum magnitude (M_{min} 6.75?)
  0.1 truncated exponential (M_{min} 6.75?)

- Other Faults
  0.8 maximum magnitude (M_{min} 6.75?)
  0.2 truncated exponential (M_{min} 6.75?)

- Background Seismicity
  1.0 truncated exponential (**M** 5.0 to M_{min})

Considerable discussion ensued regarding the details of, and the awkward name for the USGS’ “Characteristic” recurrence model used for the NSHMs. Discussion also followed on whether to change M_{min} from **M** 6.75 to **M** 6.5. It was agreed that the WGUEP M_{min} would be **M** 6.75. Earthquakes smaller than **M** 6.75 along the WFZ are assumed to occur at the same rate as background events. The background earthquake will not have a maximum magnitude of **M** 7.0, which differs from the USGS NSHM procedure.

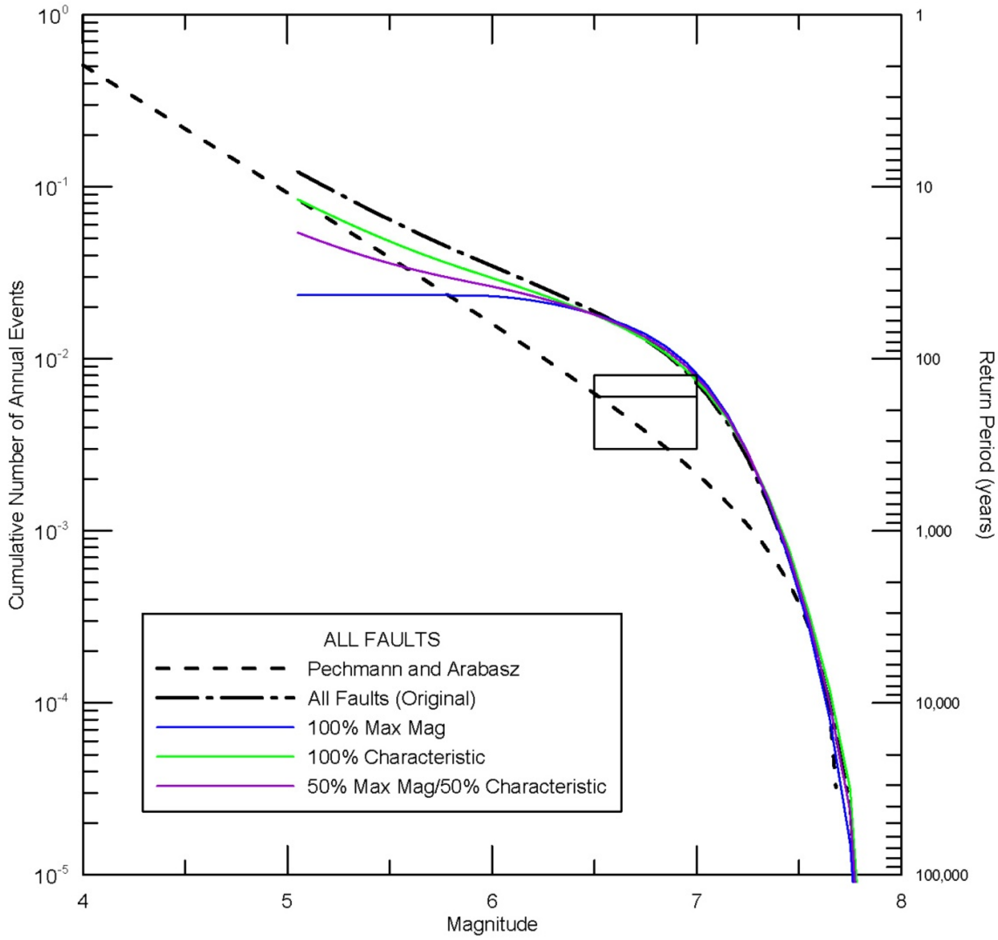


Figure 3. *Recurrence models for the Salt Lake City segment of the WFZ. The black box represents the range in recurrence-interval estimates for large magnitude earthquakes determined by Hecker (1993) using paleoseismic data.*

Table 3. *Expected return periods for ≥ **M** 5, ≥ **M** 6, and ≥ **M** 7 earthquakes for the 100% M_{max}, 100% characteristic, and 50% M_{max} / 50% characteristic models.*

Wasatch Fault Zone	Return Period (years)		
	100% M_{max}	100% Characteristic	50% M_{max}/50% Char.
M 5 and greater	98	24	39
M 6 and greater	98	72	86
M 7 and greater	200	222	215

Data Needs for Probability Calculations and Input Sensitivities

Patricia Thomas discussed the approach and data needs for the WGUEP probability calculations and input sensitivities. The approach includes the following five steps:

6. Define fault segment attributes

7. Define rupture sources and rates

8. Define background seismicity

9. Define probability model parameters

10. Probability calculations

Model data needs include:

- Geometry
  - Segment endpoints
  - Seismogenic thickness
  - Dip
- Regional moment rate constraint?
- Mean characteristic magnitude models
- Average displacement for rupture sources
- Magnitude probability density models
- Fault rupture models (rupture sources, models, weights)
- Distribution of slip for multisegment ruptures
- Background seismicity parameters
- Probability models and weights
- Probability model parameters
  - Time since last event, coefficient of variation (COV)

Next, Patricia presented the results of her preliminary probability calculations including the following (see PowerPoint presentation at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011C_Presentations.pdf for details):

- Wasatch single segment model weighted mean M_{char} magnitudes equally weighted using surface rupture length (SRL), area (A), average displacement (AD), and moment (Mo) magnitudes.
- Wasatch single segment model M_{char} magnitudes for SRL, A, AD, and Mo.
- Moment-balanced weighted mean recurrence intervals for the WFZ single segment model.
- Moment-balanced recurrence intervals for the WFZ single segment model based on SRL, A, AD, and Mo showing sensitivity to M_{char} and slip-rate relations.
- Implied slip rates from a-priori rates for the five central WFZ segments.
- Preliminary probability calculations for the WFZ single segment model using moment-balanced rates, a-priori rates (1/recurrence interval), and a closer look at probabilities for the Brigham City and Provo segments using both moment-balanced and a-priori slip rates.

Patricia then summarized the inputs required for the model (see above) and distributed a form (figure 4) showing required model inputs and the members of the Working Group responsible for providing those data.

INPUT	Responsible Person	Completed?
Wasatch RI – single central 5 segments	Chris/Nico	
Wasatch RI – multisegment ruptures on central 5 segments	Nico/Chris	
Wasatch RIs – end segments, single & multisegment ruptures		
Wasatch slip rates by segments	Mike/Chris	
Wasatch unsegmented model slip rates		
Wasatch COV		Done
O-GSL COV	Same as Wasatch	
O-GSL RIs	Susan/Jim	
O-GSL slip rates		
Final MCHAR Relations and Weights A-Faults B/C-Faults Unsegmented Wasatch (**M** 6.5-7.0) Unsegmented O-GSL? Antithetic Faults – only Area?	Susan	
Final MagRecur Models A-Faults B/C-Faults Unsegmented	Ivan	Need M_{min} for A/B/C faults
Seismogenic Thickness – BRP/CP/MRM physiographic provinces (km)	Jim/Ivan	Under further review 13 (0.3) 15 (0.4) 17 (0.3)
Fault Dips (degrees)	Tony	Done 35 (0.3) 50 (0.4) 65 (0.3)
Other Faults – length, slip rates/RIs, graben-bounding fault pair dips	Bill/Susan	
Antithetic Fault Parameters Geometry of antithetic faults with distribution, weights of coseismic/independent branches	Mike/Bill	Need final parameters on Hansel Valley
Background Seismicity Final parameters for uniform and grid points	Ivan/Mark	
Weights on time dependent /time independent	Chris and others	
Use of geodetic data	Jim/Mark/David	
Average displacement	Chris/Susan	

Figure 4. *Data needs for the WGUEP probability model and responsible WGUEP members.*

Update on WFZ Recurrence Rates and COVs

Chris DuRoss summarized the WFZ rupture scenarios (and relative weights), seismic moment (M_0) release, and coefficients of variation (COVs) on recurrence discussed at WGUEP Meeting 5 (http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Summary.pdf). Chris also presented a composite COV for the WFZ.

Working Group members discussed the methods of determining average displacement for WFZ earthquakes and rupture sources, and agreed that per-earthquake displacement should be measured using an analytical half ellipse scaled to displacement observations (e.g., Chang and Smith, 2002). This method helps account for sparse displacement observations or those measured near mapped segment boundaries. Working Group members recommended a weighted mean for each earthquake source, that is, the mean of the mean displacement per earthquake on the source.

The composite COV determined for the WFZ is based on the following procedure:

1. Compile inter-event recurrence probability density functions (PDFs) in one place.
   - For example, Brigham City B4–B3, B3–B2, and B2–B1, plus Weber segment W4–W3, W3–W2, etc. (n = 16 inter-event recurrence intervals [RIs]).
   - RI PDFs used are those filtered for some minimum value (see DuRoss, 2011).
   - The elapsed time since the MRE on each segment is not included as a recurrence interval.

2. Sample recurrence data. In each simulation (n = 10 k).
   - For each of the 16 inter-event RI PDFs, randomly select a single recurrence value (e.g., B4–B3) and add to group of recurrence values.
   - Each simulation (sim) results in a set of 16 inter-event RIs.
   - Composite COV (per sim) = standard deviation (stdev) of all RIs / mean of all RIs.
   - A per-segment COV (per sim, per segment) = stdev of per-segment RIs / mean of per-segment RIs.

3. The composite COV values computed in each simulation are then compiled and plotted in probability space.

When broken out by segment (colored PDFs in figure 5), the COV estimates determined using the above method are nearly identical to those discussed at WGUEP meeting 5. Minor differences relate to using the inter-event RIs filtered for minimum recurrence. If these individual-segment COV PDFs are summed, the resulting PDF (black dashed line in figure 5) has a mean and 2σ uncertainty of 0.4 ± 0.4. The large range reflects the equal weight given to the COV determined for each segment. For example, the poorly constrained Nephi segment COV (based on two inter-event RIs) of 0.2 ± 0.4 and the relatively well constrained Weber segment COV (based on four inter-event RIs) of 0.4 ± 0.3 both account for 1/5 of the data, or 20%.

The composite COV is 0.5 ± 0.1 (2σ), which reflects the compiled 16 individual-event RIs and single COV calculation (per simulation). Using the example above, the two Nephi segment inter-event RIs now account for 2/16 or 12.5% of the data, whereas the four RIs for the Weber segment are 4/16 or 25% of the data. Thus, each inter-event recurrence interval is weighted equally. This method accounts for the full shape of each inter-event RI, but these uncertainties are minimized as the 16 RIs are combined. Using the full range of the data, the WFZ composite COV is 0.5 ± 0.2, similar to the global COV used by California earthquake-forecast working groups (e.g., the Working Group on California Earthquake Probabilities). However, the shape of the WFZ composite COV PDF suggests a symmetric distribution, rather than the asymmetric distribution used by the California working groups. Working Group members agreed to use the 0.5 ± 0.2 COV for the central WFZ (and other faults); however, additional discussion is needed regarding whether a symmetrical or asymmetric distribution should be applied.

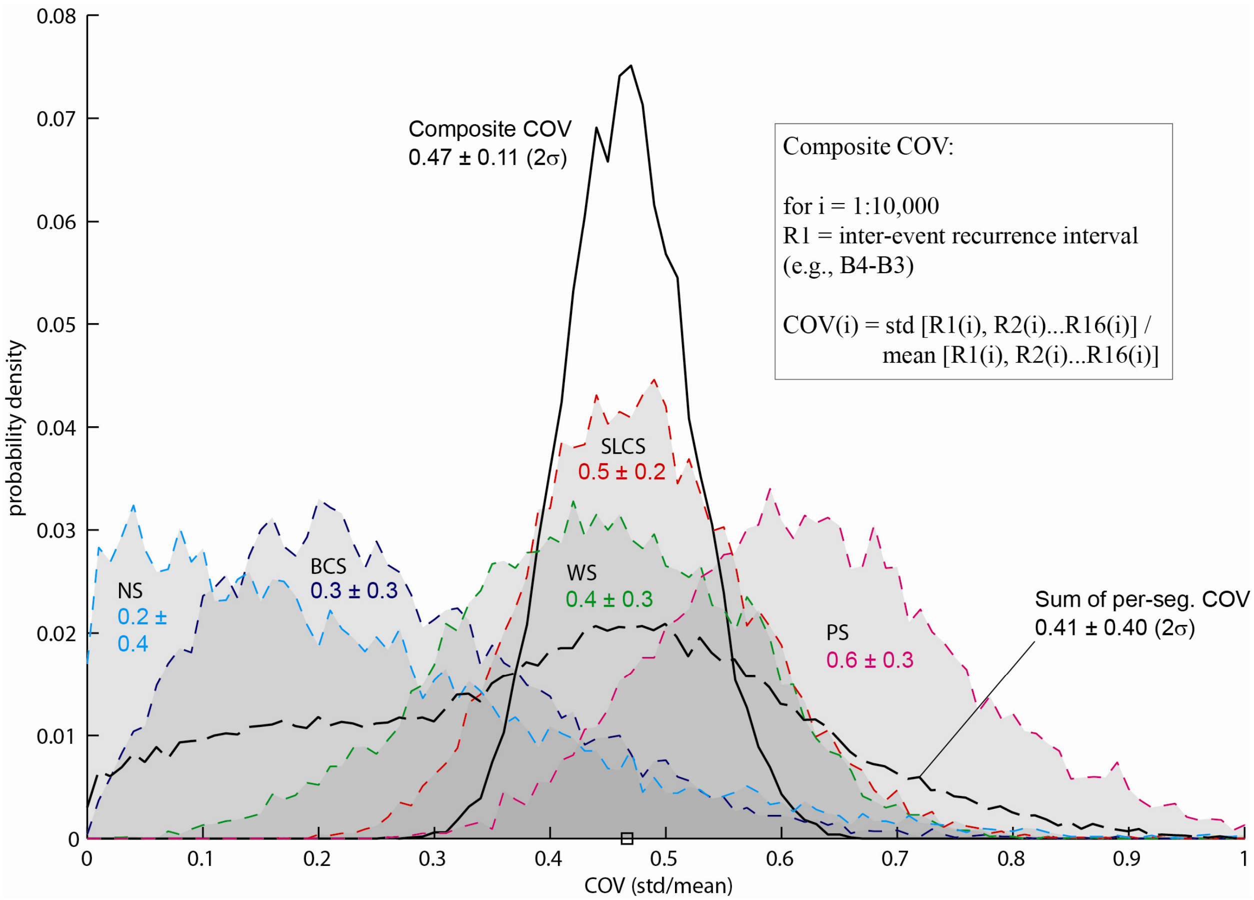


Figure 5. *Composite COV for the five central segments of the WFZ.*

Update on "Other Faults" Database

Bill Lund reviewed the current status of the Wasatch Front Region (WFR) "Other Fault" database (table 4). The USGS Quaternary Fault and Fold Database of the United States (QFFDUS) includes a total of 112 faults or fault sections within the WGUEP WFR, exclusive of the 10 segments of the WFZ. Of those 112 faults/fault segments, 53 have been retained in the "Other Fault" database and will be modeled in a time independent manner for the WGUEP earthquake forecast. The remaining 59 faults/fault sections have been eliminated from further consideration in the WGUEP modeling process through application of the following three screening criteria:

Parameters		Retained Faults	Deleted Faults
Total	112	53	59
<0.2 mm/yr		37	59
> 0.2 mm/yr < 1.0 mm/yr		12	–
> 1.0 mm/yr < 5.0 mm/yr		1	–
Unknown		3	–
Historical		1	–
Latest Quaternary < 15 ka		37	4
Late Quaternary < 130 ka		7	6
Middle Quaternary < 750 ka		7	20
Quaternary < 1.8 Ma		1	29
0 – 10 km		8	28
11 – 20 km		16	15
21– 30 km		13	7
31 – 40 km		6	6

Table 4. *Parameters of faults exclusive of the ten WFZ segments within the WGUEP WFR as of 11/17/2011.*

1. Faults less than 15 km long if not linked – **M** 6.5 rule (faults less than 15 km long are considered unlikely to generate a ≥ **M** 6.5 earthquake, and therefore will be accommodated in the WGUEP earthquake forecast model as background earthquakes).

2. Faults categorized on the QFFDUS as < 750 ka or older if not plausibly linked to younger faults.

3. Wisdom of the group – which sometimes trumped criteria 1 and 2.

Although approaching final form, the "Other Fault" database remains under review and may undergo some additional modification before WGUEP Meeting 7 in February 2012. In particular, the Joes Valley and East Canyon faults presently in the database will receive additional careful scrutiny, as will the Snow Lake graben, which presently is not in the database, but which exhibits many characteristics similar to those of the Joes Valley faults.

Update on Calculating Moment Magnitudes for WGUEP Faults

Significant epistemic uncertainties complicate the determination of earthquake moment magnitude for Basin and Range (BRP) normal faults. For example, for the central WFZ, a **M** discrepancy exists where **M** based on average displacement (AD) or seismic moment (M_0) exceeds that based on surface rupture length (SRL) or area (A). This difference in turn results in a significant discrepancy in M_0 release on the central WFZ, which affects moment-balanced models of earthquake recurrence and slip rate. However, for the WFZ, it is difficult to consistently reduce this discrepancy because of (1) consistently large vertical displacements per earthquake (using vertical displacement in **M** calculations and fault-parallel displacement in M_0 calculations), (2) insufficient data to consistently apply the average-displacement correction of Hemphill-Haley and Weldon (1999) and the limited effect of this method, (3) a poor basis for increasing SRLs beyond mapped segment boundaries, and (4) less robust normal-fault-type empirical relations (compared to all-fault-type relations; Wells and Coppersmith, 1994), which if used, help reduce the discrepancy. In addition, epistemic uncertainties may stem from the **M** regressions rather than the input data because of (1) a small-earthquake bias in historical catalogs and different scaling relations for small versus large earthquakes (Stirling and others, 2002), and (2) differences in **M** estimates depending on the strain-rate environment (Anderson and others, 1996).

The Basin and Range Province Earthquake Working Group II (BRPEWGII), which convened in November, 2011, prior to WGUEP Meeting 6, discussed the **M** discrepancy as related to BRP normal faults and its implications for the USGS NSHMs. Following a discussion of possible sources of the **M** discrepancy, the BRPEWGII recommended the following to the USGS:

*To better address the epistemic uncertainties in determining M_{max} (**M**) for BRP normal faults, the USGS should consider using the following multiple regression relations to determine M_{max} for BRP faults in the NSHMs:*

- *Wells and Coppersmith (1994) – SRL (all fault types)*
- *Wells and Coppersmith (1994) – SRL (normal fault types)*
- *Wells and Coppersmith (1994) – rupture area (A) (all fault types)*
- *Stirling and others (2002) – censored instrumental (SRL)*
- *Anderson and others (1996) – slip rate*

The WGUEP considered the BRPEWGII recommendation, and revised the regressions used in the two-category approach discussed at WGUEP Meeting 5 in June 2011, http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Summary.pdf). The Meeting 5 approach included the following regressions and weights:

Category A faults (3+ paleoseismic sites) (June 2011)	Weight
• Wells and Coppersmith (1994) – SRL (all fault types)	0.25
• Wells and Coppersmith (1994) – A (all fault types)	0.25
• Wells and Coppersmith (1994) – AD adjusted using Hemphill-Haley and Weldon (1999)	0.25
• Hanks and Kanamori (1979) – M_0	0.25

Category B/C faults (0–2 paleoseismic sites) (June 2011)	Weight
• Wells and Coppersmith (1994) – SRL (all fault types)	0.5
• Wells and Coppersmith (1994) – A (all fault types)	0.5

At WGUEP Meeting 6, members considered the conclusions of the BRPEWGII and developed the following approach:

Category A faults (2+ paleoseismic sites) (November 2011)	Weight
• Hanks and Kanamori (1979) – M_0	0.3
• Stirling and others (2002) – SRL (censored instrumental)	0.3
• Wells and Coppersmith (1994) – SRL (all fault types)	0.2
• Wells and Coppersmith (1994) – A (all fault types)	0.2

Category B/C faults (all others) (November 2011)	Weight
• Stirling and others (2002) – SRL (censored instrumental)	0.4
• Wells and Coppersmith (1994) – SRL (all fault types)	0.2
• Wells and Coppersmith (1994) – A (all fault types)	0.2
• Anderson and others (1996) – slip rate	0.2

The updated approach includes four regressions when paleoseismic data are available (category A faults). The greatest weight is given equally to the Hanks and Kanamori (1979) M_0 regression—a well-accepted regression that estimates **M** based on M_0, and thus accounts for AD and A—and the Stirling and others (2002) regression for SRL based on their censored-instrumental data. The Stirling and others (2002) regression accounts for potential differences in small versus large earthquakes and has the best fit to the relatively large WFZ magnitudes based on AD or M_0. The Wells and Coppersmith (1994) regression on AD (either with or without an adjustment based on Hemphill-Haley and Weldon [1999]) was not included because of the limited data used to define the regression, as well as issues related to different displacement measurement types (e.g., vertical and horizontal, versus net displacement). Relatively less weight is given to the Wells and Coppersmith (1994) all-fault-type regressions on SRL and A. Although normal faults may behave differently than strike-slip or reverse faults, the Wells and Coppersmith (1994) normal-fault-type regressions were not included, owing to the limited data used to determine the regressions (e.g., only 15 normal-faulting earthquakes have SRL information compared to 77 all-slip-type earthquakes).

For faults with little to no paleoseismic data (category B/C faults), four regressions are included to account for uncertainties arising from the apparent discrepancy between displacement- and length-based **M** estimates. The Stirling and others (2002) regression is given the most weight considering its good agreement with the WFZ M_0-based **M** estimates, and because it is the only regression present that appears to account for the **M** discrepancy. Equal, but less weight is given to the Wells and Coppersmith (1994) all-fault-type regressions on SRL and A, as well as the Anderson and other (1996) regression, which accounts for slip rate. Anderson and others (1996) found that including slip rate with SRL in the regression model provided a better fit to the data than just SRL alone, perhaps due to differences in fault behavior in different tectonic regimes (high versus low strain-rate environments). Normal-fault-type regressions (Wells and Coppersmith, 1994) were not included for reasons discussed above.

Further discussion is required on this topic to determine if the Working Group is comfortable with the weights assigned to the regressions recommended for the B and C category faults.

Path Forward on Use of Geodetic Data

Based on a review of Christine Puskas' comparison of geodetic, historical earthquake, and geologic moment rates across the Wasatch Front (see WGUEP Meeting 5 Summary at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Summary.pdf), Jim Pechmann concluded that for Christine's northern and central boxes, geodetic moment is a factor of two to three times (depending on the rupture model used) greater than geologic moment. For the southern box, geodetic moment is a factor of five to ten times greater than geologic moment. The reasons for these discrepancies remain unclear, but may be due in part to missed contributions to geologic moment rates from faults not included in the analysis. Based on Jim's review, the Working Group concluded at Meeting 5 that the geodetic data could provide an estimate of extension in a volume of crust across a region (WFR), and therefore provide a check on geologic rates. Additionally, areas with large discrepancies could be targeted for further study to resolve significant differences. However, the geodetic data are not sufficiently robust to allow geodetic extension to be partitioned among individual faults.

At Meeting 6, Ivan stated that geodetic data will likely not be a direct input to the WGUEP probability calculations. Mark Petersen noted that geodesists now expect geodetic data to be incorporated in earthquake probability analyses, and if we don't use the data available for the Wasatch Front, we will still need to acknowledge its existence and explain why we did not use it. Mark then turned the discussion to the high horizontal slip measured across the southern Wasatch Front. Tony Crone stated that the higher rates may be due to post seismic relaxation following an earthquake cluster, or possibly deformation of the more ductile rock units (salt and gypsum) found in the southern Wasatch Front area.

Jim Pechmann questioned why we should assume that all of the horizontal slip is on the WFZ, and noted that we are really looking at a volume of crust with several Quaternary-active faults within it. David Schwartz stated the WGUEP should use the geodetic data as an upper bound and that we should convert available geologic slip rates to horizontal slip and then make a comparison of the horizontal slip data with the geodetic data to evaluate the size of the discrepancy. David volunteered to make the comparison. Patricia Thomas noted that the extension rates are within the uncertainty limits assigned to the WFZ geologic slip rates, and therefore will be covered in the probability calculations. Susan Olig wondered how much of the geodetic slip may be aseismic, and if there is a way to determine if aseismic slip is occurring, and if so, how much.

Ivan outlined a path forward that includes obtaining a robust slip rate for the WFZ and using that rate as a low-weight branch on the WFZ model. Jim, with the assistance of Mark, will analyze the difference between the geodetic and geologic rates and the Working Group can then decide how to proceed.

Spatial Smoothing Issues

This discussion centered on whether the WGUEP wants to include a uniform background zone, in additional to Gaussian smoothing to account for non-stationarity in the historical record. That is, should we allow for the possibility that background earthquakes in the WFR could occur in locations where there have not been events in the historical record? Both approaches could be weighted as was done for the Salt Lake Valley microzonation maps developed by Wong and others (2002). The USGS smoothes background seismicity on the NSHMs using an isotropic smoothing function, except for three zones, where they use an anisotropic smoothing function: (1) Brawley seismic zone, (2) Creeping section, San Andreas fault, and (3) Mendocino seismic zone (all in California). The discussion then centered on whether the WGUEP should use isotropic, anisotropic, or a combination of the two in the WFR. Ivan stated that he would discuss that issue and also the appropriate smoothing kernel to use with Bob Youngs (Amec Geomatrix Consultants, Inc.).

M_{max} for Background Earthquakes

The discussion centered on what M_{max} should be considered for the background earthquake. Previous studies in the Wasatch Front have generally used **M** 6.5 ± 0.25. The USGS uses a M_{max} of **M** 7.0, which seems too high. The answer to the question depends on the minimum M_{max} for faults, the evidence for which (scarps) could be observed at the surface after repeated earthquakes. The prevailing thinking was that **M** 6.5 was too low. Hence, at WGUEP Meeting 5 Ivan suggested a preliminary M_{max} of **M** 6.75 ± 0.25 (see WGUEP Meeting 5 Summary at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2011B_Summary.pdf).

Discussion then focused on whether a M_{max} of **M** 6.5 or 6.75 is more appropriate for background earthquakes in the WFR; the WGUEP settled on **M** 6.75, because smaller events may not be observed in trenches and hence would go undetected.

Modeling Graben-Bounding Fault Pairs

The WGUEP WFR includes a number of graben-bounding (antithetic) fault pairs (WFZ Salt Lake City segment/West Valley fault zone, WFZ Provo segment/Utah Lake faults, East Cache fault/West Cache fault zone, Hansel Valley fault/North Promontory fault, Joes Valley graben bounding faults, and Eastern Bear Lake fault/Western Bear Lake fault) that are too close together to avoid intersecting at depth.

- Faults closer than 17 km will intersect if both dip 60°
- Faults closer than 25 km will intersect if both dip 50°
- Faults closer than 36 km will intersect if both dip 40°

On past iterations of the NSHMs, antithetic fault pairs were each projected below their intersection to a depth of 15 km and earthquake magnitudes calculated for each fault based on area. This process overestimates hazard because if a "master" fault intersects and truncates its antithetic fault, the correspondingly smaller area of the antithetic fault would result in a lower earthquake magnitude and hazard.

The BRPEWGII also considered the issue of antithetic fault pairs as they apply to the next update of the NSHMs (Issue G2) and formulated the following recommendations to the USGS:

- *USGS should explore using metrics (such as length, topographic relief, and overlap) to guide selection of master and subsidiary faults.*
- *Evaluate dataset for overlapping relations to select master fault based on length.*
- *Evaluate using aspect ratio (length/width) for individual fault pairs.*
- *Where data allow, structural throw should be used rather than topographic relief.*
- *Evaluate using length x throw as a parameter for selecting master fault.*
- *Subsurface data (e.g., seismic reflection) should be used to guide master fault selection, where available.*
- *Where available data do not give a clear indication of master vs. subsidiary fault, model both alternatives using a logic tree approach.*
- *For truncated faults use rupture area (rather than SRL) to determine M.*

The WGUEP will review the BRPEWGII recommendations to the USGS regarding antithetic fault pairs for possible use in the WGUEP modeling process.

Dip Angles for Basin and Range Normal Faults

The BRPEWGII also examined and discussed the issue of dip angle for BRP normal faults with respect to the next update of the NSHMs (Issue G4). Based on the recommendation from BRPEWGI (Lund, 2006), the current USGS NSHMs use a dip value of 50°±10° for normal faults in the BRP. The question considered by BRPEWGII was "is the 50° dip value and the ±10° uncertainty range valid and acceptable to cover the probable range of dips for BRP normal faults?" At the workshop, a review of geological, seismological, and geodetic data for faults in the BRP and in other selected regions worldwide provided insight into the dip of normal faults in continental crust. Following this review and discussion, the BRPEWGII formulated the following recommendations to the USGS:

- *Following a review of published data summarizing the dips of normal faults in the BRP and worldwide, the BRPEWGII concludes that a dip of 50° ± 15° best represents the range of dips for normal faults in the BRP. The BRPEWGII recommends this range be used in updates of the NSHMs; the 50° value defines the mean dip value and the ± 15° range represents the 5% and 95% percentiles.*

- *For those faults having geological, geophysical, seismological, or geodetic data that convincingly constrains a specific fault's dip within seismogenic depth, the NSHMs should use these fault-specific data to calculate the fault's hazard.*

- *The BRPEWGII recommends that the USGS evaluate the impact of increasing the range of recommended fault dips (from ± 10° to ± 15°) on the overall hazard.*

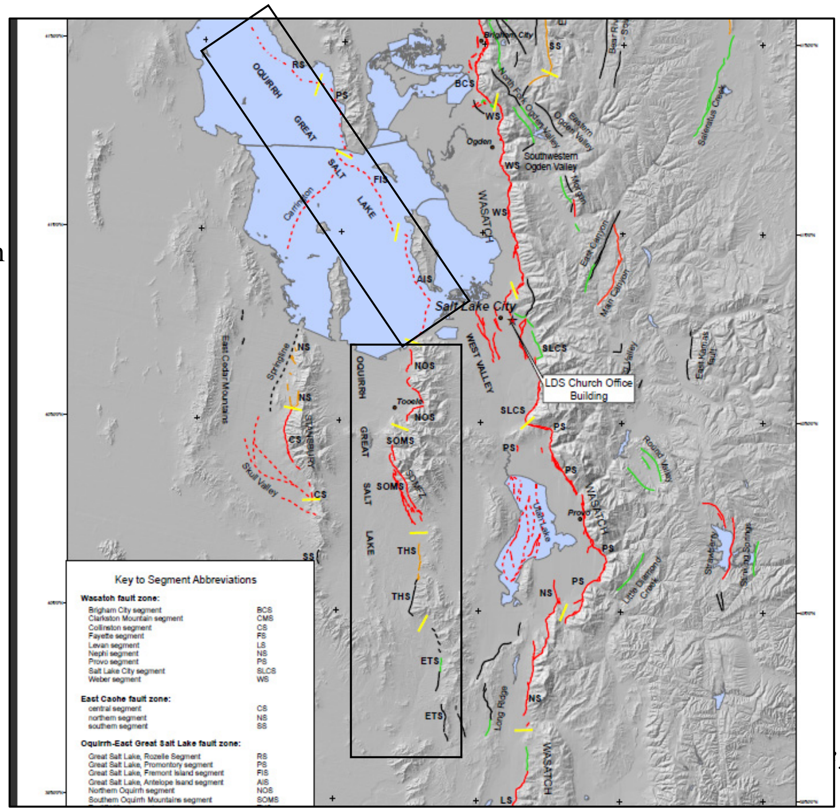
- *USGS should also evaluate whether the range in fault dips determined from global data is better represented by non-Poissonian distribution around the mean value versus assuming a simple Poissonian distribution*

The WGUEP will review the BRPEWGII recommendations to the USGS for possible use in the WGUEP modeling process.

Oquirrh-Great Salt Lake Fault Zone

Susan Olig reviewed the current segmentation model for the Oquirrh-Great Salt Lake fault zone (O-GSLFZ) (figure 6):

O-GSLFZ SEGMENTS
Rozelle (RS) – 25 km
Promontory (PS) – 25 km
Fremont Is. (FIS) – 25 km
Antelope Is. (AIS) – 35 km
No. Oquirrh (NOS) – 30 km
So. Oquirrh (SOMS) – 31 km
Topliff Hills (THS) – 26 km
East Tintic (ETS) – 35 km



fault

Susan then reviewed the timing information available for the most recent surface-faulting earthquake on each of the proposed O-GSLFZ segments (table 5), and the Great Salt Lake fault zone rupture scenarios and weights developed at WGUEP Meeting 4 (table 6). She then presented two new strawman rupture models with different weights for a combined O-GSLFZ (table 7).

Following discussion, the WGUEP expressed a general preference for the Strawman 2 weights, although Chris DuRoss felt that a rupture scenario that included an AI+NO multisegment rupture should also be included in the model. The possibility of having unsegmented rupture scenarios of various lengths was also discussed. Due to time constraints the discussion was cut short and Susan and Jim Pechmann were charged with revising the model to address the WGUEP discussion comments.

Table 5. *Age of youngest surface-faulting along segments of the Oquirrh-Great Salt Lake fault zone.*

	Fault Segment	Youngest Event	Penultimate Event	Older Events?[3]
Great Salt Lake fault[2]	Rozelle (RZ)	Holocene?	?[3]	?[3]
	Promontory (PY)	Holocene?	?[3]	?[3]
	Fremont Island (FI)	3,150 (+240, -210)	6,410 (+210, -210)	< 11,430 (+610, -450)
	Antelope Island (AI)	590 (+200, -240)	6,170 (+240, -230)	9,900 (+250, -300)
	Northern Oquirrh (NO)[4]	6330 (4960 to 7650)	20,300 - 26,400	> > 33,000
	Southern Oquirrh (SO)[5]	1,300 to **4,830**[6]	20 to 50 ka[6]	shortly after 42 ± 8; shortly after 75 ± 10 ka; ca. 92 ± 14 ka[6]
	Topliff Hills (TH)	> 15,000[7] or < 15,000[8]	?[3]	?[3]
	East Tintic (ET)	> > 15,000 (middle to late Pleistocene)[9]	?[3]	?[3]

Table 6. *Great Salt Lake fault zone rupture scenarios and weights from WGUEP Meeting 4*

Rupture Scenarios	WGUEP Weights
R, P, *FI, AI*	***0.75***
R, P, FI+AI	**0.1**
Unsegmented	**0.15**

R = Rozelle segment, P = Promontory segment, FI = Fremont Island segment, AI = Antelope Island segment; italics indicates time-dependent model considered for that rupture source.

Table 7. *Strawman Oquirrh-Great Salt Lake fault zone rupture model.*

	Rupture Scenarios	Strawman 1 Weights	Strawman 2 Weights
1	RZ, PY, *FI, AI,* NO+SO, TH, ET	*0.40*	*0.25*
2	RZ, PY, *FI, AI,* NO, SO, TH, ET	*0.25*	*0.40*
3	RZ, PY, FI+AI, NO, SO, TH, ET	0.10	0.10
4	RZ, PY, *FI, AI,* NO, SO+TH, ET	0.10	0.10
5	Unsegmented (floating)	0.15	0.15

RZ = Rozelle segment, PY = Promontory segment, FI = Fremont Island segment, AI = Antelope Island segment, NO = Northern Oquirrh, SO = Southern Oquirrh, TH = Topliff Hills, ET = East Tintic; italics indicates time-dependent model considered for that rupture source.

TASK LIST

1. Complete revision of the historical earthquake catalog (Walter/Jim).
2. Decluster catalog and calculate recurrence for background seismicity correcting for magnitude bias (Mark/Walter/Ivan).
3. Finalize selection of recurrence models and weights (Ivan).

4. Finalize COV and uncertainties for WFZ – asymmetric or symmetric (Chris).
5. Finalize RIs for single and multi-segment ruptures on central WFZ (Chris/Nico).
6. Finalize slip rates for end segments of WFZ (Mike/Chris).
7. Finalize rupture model, RIs, slip rates, and COV for O-GSLFZ (Susan/Jim).
8. Finalize M_{max} procedures (Susan).
9. Finalize seismogenic crustal thicknesses for west and east of WFZ (Jim/Ivan).
10. Finalize parameters for "Other Faults" (Bill).
11. Finalize parameters for antithetic rupture of Hansel Valley fault (Mike/Bill).
12. Finalize weights of time-dependent versus time-independent models for WFZ and O-GSLFZ (Chris/Susan/Jim).
13. Finalize average displacements for calculating **M** for central WFZ (Chris/Susan).
14. Compare geologic horizontal slip rates with geodetic rates across Wasatch Front (David/Jim/Mark).
15. Finalize approach for background seismicity (Ivan/Mark).

REFERENCES

Presenters did not provide complete citations for the references given in their presentations and reported in these minutes.

NEXT MEETING

The next WGUEP meeting is scheduled for February 16–17, 2012, at the Utah Department of Natural Resources Building (1594 West North Temple, Salt Lake City, Utah).

ATTACHMENT 1

Attendance

Working Group on Utah Earthquake Probabilities
Meeting 6

Walter Arabasz, UUSS
Tony Crone, USGS
Chris DuRoss, UGS
Mike Hylland, UGS
Nico Luco, USGS
Bill Lund, UGS, Coordinator
Susan Olig, URS Corporation
James Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
Dave Schwartz, USGS
Bob Smith, UUGG*
Patricia Thomas, URS Corporation
Ivan Wong, URS Corporation, Chair

*Member Absent

Others presenting or assisting the Working Group
Steve Bowman, UGS Liaison to WGUEP

ATTACHMENT 2

REVISED AGENDA*
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #6
Thursday/Friday, 17 & 18 November 2011
Utah Department of Natural Resources Building, Room 2000 (2nd floor)
1594 West North Temple, Salt Lake City

Thursday, 17 November

8:00 – 8:30	Continental Breakfast	
8:30 – 8:45	Welcome	Bill
	Overview of Agenda	Ivan
	Update on Consensus Wasatch Front Earthquake Catalog	Walter/Jim
	Recurrence Models (Issue S1)	Ivan
	Overview of Methodology and Data Needs	Patricia
	Update on Final Wasatch Central Segment Recurrence Rates and COVs	Chris
	Update on Other Faults (Issue G3)	Bill
	Calculating M_{max} for Faults (Issue G1)	Susan/Chris
5:00	Adjourn	

Friday, 18 November

7:30 – 8:00	Continental Breakfast	
	Path Forward on Use of Geodetic Data	Ivan
	Spatial Smoothing (Issue S2)	Mark
	Modeling Antithetic Faults (Issue G2)	Mike
	Fault Dips (Issue G4)	Tony
	M_{max} for Background Earthquakes	Ivan
	Historical Versus Geologic Rates (Issue S3) (Not discussed)	Ivan
	Oquirrh-Great Salt Lake Fault	Susan
	Open Discussion and Schedule	All
3:00	Adjourn	

WGUEP Members

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

Other Participants

Steve Bowman, UGS

*Topic discussions at this meeting were free roaming. Topics discussed on the first and second day are listed above; however, discussion length and start and stop times were variable.

SUMMARY
SEVENTH MEETING
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Thursday & Friday, February 16 & 17, 2012
Utah Department of Natural Resources Building, Room 1040-1050
1594 West North Temple, Salt Lake City

WELCOME AND INTRODUCTION

Working Group on Utah Earthquake Probabilities (WGUEP) Coordinator Bill Lund called the seventh WGUEP meeting to order at 8:30 a.m. After welcoming the Working Group members and UGS staff (attachment 1), Bill turned the meeting over to Ivan Wong (WGUEP Chair) who reviewed the meeting agenda (attachment 2), recapped WGUEP progress to date, and reviewed the current WGUEP task list, which included the following:

1. Complete revision of the historical earthquake catalog (Walter/Jim).
2. Decluster historical earthquake catalog and calculate recurrence for background seismicity correcting for magnitude bias (Mark/Walter/Ivan).
3. Finalize selection of recurrence models and weights (Ivan).
4. Finalize coefficient of variation (COV) and uncertainties for the Wasatch fault zone (WFZ) – asymmetric or symmetric (Chris).
5. Finalize recurrence intervals (RIs) for single and multi-segment ruptures on central WFZ (Chris/Nico).
6. Finalize slip rates for end segments of the WFZ (Mike/Chris).
7. Finalize rupture model, RIs, slip rates, and COV for Oquirrh-Great Salt Lake fault zone (O-GSLFZ) (Susan/Jim).
8. Finalize M_{max} procedures (Susan).
9. Finalize seismogenic crustal thicknesses for west and east of the WFZ (Jim/Ivan).
10. Finalize parameters for "Other Faults" (Bill).
11. Finalize parameters for antithetic rupture of Hansel Valley fault (Mike/Bill).
12. Finalize weights of time-dependent versus time-independent models for WFZ and O-GSLFZ (Chris/Susan/Jim).
13. Finalize average displacements for calculating magnitudes (**M**) for central WFZ (Chris/Susan).
14. Compare geologic horizontal slip rates with geodetic rates across Wasatch Front (David/Jim/Mark).
15. Finalize approach for background seismicity (Ivan/Mark).

TECHNICAL PRESENTATIONS

The meeting then moved to a series of technical presentations and issue updates.

Available PowerPoint presentations from the meeting are at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2012A_Presentations.pdf. Note that not all presentations included a PowerPoint.

Thursday, February 16

- Update on Consensus Wasatch Front Catalog – Walter Arabasz and Jim Pechmann
- Multi-Segment Ruptures on Normal Faults – Dave Schwartz
- Working Group on Utah Earthquake Probabilities Paleoseismology Subgroup Update – Chris DuRoss
- The Wasatch Fault Zone End Segments (Malad City, Clarkston Mountain, Collinston, Levan, and Fayette), Slip Rate and Length, Model Distributions and Weights – Mike Hylland
- Oquirrh-Great Salt Lake Fault Zone Revisited – Susan Olig and Jim Pechmann
- Other Fault Parameters – Bill Lund
- Final Recurrence Models and Weights – Ivan Wong

Friday, February 17

- Antithetic Fault Parameters – Mike Hylland
- Maximum Earthquake Focal Depths in the WGUEP Wasatch Front Region – Jim Pechmann
- Smoothing of Background Seismicity – Ivan Wong
- Evaluation of Geodetic Models in Northern California – Mark Petersen
- UCERF3 Evaluation of Geodetic Models in California – Ivan Wong
- Probability Calculations and Input Sensitivities – Patricia Thomas

ISSUE DISCUSSIONS

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

Update on Consensus Wasatch Front Earthquake Catalog

Walter Arabasz presented an update on the effort to compile a consensus Wasatch Front Region (WFR) earthquake catalog. The principal points of the presentation included:

- Information items
    - Efforts similar to the WGUEP are underway to rigorously derive earthquake rate information from the University of Utah's earthquake catalog as part of the Blue Castle project for a proposed nuclear power plant near Green River, Utah.
    - Final report for the Central and Eastern United States Seismic Source Characterization for Nuclear Facilities is now available at http://www.ceus-ssc.com/project_report.html. (The report contains abundant details on the state of practice for using earthquake catalogs and paleoseismological data in seismic source characterizations.)

- The data set of reliable moment magnitudes for the Utah region totals more than 100 earthquakes. These measurements are useful not only for the events themselves, but are also critical for assessing the relation between M_L and M_C in the University of Utah Seismograph Stations' (UUSS) catalog with M_W.
    - pre-1962: N=2 (Hansel Valley main shock and after shock)
    - 1962-1980: N=7 (Pechmann, unpublished compilation; ~same sources as Pancha and others [2006], Doser and Smith [1982] values excluded)
    - 1981-2003: N=52 (Pechmann and others, 2007, 2010), nine overlap with Whidden and Pankow (2012)
    - 1997-2011: N=48 (Whidden and Pankow, 2012), 25 overlap with Herrmann and others (2011)

      N=29 (Herrmann and others, 2011)

- Work on magnitude conversions and corresponding uncertainties (historical: M_L (I_o); instrumental: M_L, M_C, and M_W) – Walter reviewed (1) why these uncertainties are important, notably because they bias earthquake-rate estimates, and (2) approaches to account for the magnitude-conversion uncertainties in earthquake-rate calculations.

- Update on unifying UUSS and National Seismic Hazard Maps (NSHM) catalogs (and magnitudes, see table 1, below)
    - Historic catalog (1850 -1962)
    - Instrumental catalog (1962 -2010)

- Target for passing catalog to URS Corporation/U.S. Geological Survey "analysts"
    - Attempting to complete before mid-March – likely to take at least a month longer
    - Decision on declustering method to be made by analysts

Mark Petersen asked whether or not we should try smoothing to **M** 3 events? Walter's opinion was that we should because of the sparse amount of available data; Mark and Ivan agreed.

Table 1. *Unifying UUSS and NSHM Catalogs.*

Time Period	**UUSS**	**NSHM**	**Pancha and others (2006)**
1850 - JUN 1962 No. of Events	462 307 (M_{int}) 140 (no mag)	143	68 Reconciling Magnitudes
JUL 1962 - SEP 1974	866 M_C, M_L (347 ≥ M2.5)	226 mbneic, M_L	22 Variance weighting?
OCT 1974 - DEC 1980	5,256 M_C, M_L (452 ≥ M2.5)	47 Mostly M_L (reliant on UUSS)	5
JAN 1981 - DEC 2010	49,737 M_C, M_L, M_W (3,337 ≥ M2.5)	371	19

Multi-Segment Ruptures on Normal Faults

David Schwartz made a presentation on three very large normal-fault earthquakes (Sanriku **M** 8.6, Kuril **M** 8.1, and Tohoku (normal) **M** 7.7; A, B, and C respectively on figure 1) associated with the Japan trench subduction zone. All three earthquakes are well located and occurred where outer-rise/outer-slope gravity anomalies are positive and large in the subducting Pacific plate (figure 1). David stated that the Tohoku (megathrust) earthquake has caused some in the seismic-hazard community at large to ask questions such as:

- How do we know that we have seen the largest possible earthquake?
- Is fault segmentation dead?
- Is the characteristic earthquake model dead?

David recognizes that these normal fault earthquakes occurred within a tectonic setting very different from the one that is operative in the WGUEP study area, but felt that it was important to discuss these events to demonstrate that we are thinking about the issue of capturing the largest possible event in our earthquake model.

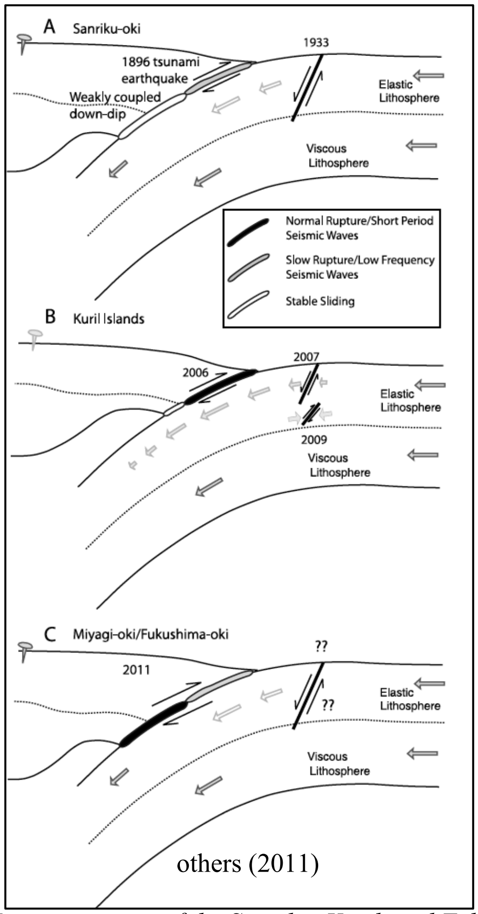


Figure 1. *Tectonic setting of the Sanriku, Kuril, and Tohoku (Fukushima) normal fault interpolate earthquakes in the flexing Pacific plate as it subducts at the Japan trench.*

Tony and Ivan felt that whatever earthquake we select as the model for a possible "Black Swan" earthquake (extremely rare, almost impossible event with a very low probability) for the WGUEP study area, it should be based on an earthquake that occurred within the continental crust (e.g., the 1887, estimated **M** 7.4 Sonoran [Pitaycachi] earthquake), and not one at a convergent plate margin. Ivan recommended limiting our largest rupture to a two segment rupture on the Wasatch fault, and to be prepared to defend that decision as a realistic maximum. Dave stated that there is a movement to do away with segmented earthquake models, to which Ivan replied that our earthquake source model will include a floating M 6.5-7.5 earthquake along the Wasatch fault probably weighted at 10 percent. Walter stated that it is important in our final report to remind our readers about the difference between multisegment ruptures on strike-slip and normal faults. Dave volunteered to write up this section of the final technical report.

Following up on David's discussion regarding identifying the largest possible earthquakes in our source model, Mark revisited the question of maximum magnitude for a background earthquake in the WGUEP study area. The previously agreed upon maximum was **M** 6.75 $\pm$ 0.25; however, Mark questioned whether all **M** 6.75 earthquakes in the WGUEP study area have produced ground rupture. If not, which is Mark's opinion, then an unknown number of large earthquakes are not represented in the geologic record in the study area. After discussion, it was determined as an experiment to increase the maximum magnitude of the background earthquake to **M** 7, and to calculate the recurrence for both fault and background events to see if the increased magnitude creates an earthquake bulge for the study area.

Paleoseismology Subgroup Update

Chris DuRoss presented a Paleoseismology Subgroup update on model parameters for the central WFZ. Chris discussed (1) final RIs per segment, (2) a composite RI for the central WFZ, (3) time-dependent and time-independent weights for the central WFZ segments, (4) revised displacement per rupture (and source) calculation methods and values, (5) vertical slip rate estimates per segment, and a strawman model for which slip rate values to include, and (6) a final strawman model for which magnitude regressions to include (with weights).

The Paleoseismology Subgroup had previously assigned strawman weights for the time-dependent (0.8) and time-independent (0.2) branches of the logic tree, which the working group revised to 0.7-time dependent, 0.3-time independent (table 2). The consensus of the group was that a time dependent model likely is more appropriate for the WFZ and there is sufficient paleoseismic data to model the central WFZ in a time-dependent manner. In contrast, weight given to the time-independent branch considers the short (~0.5 kyr) and long (~2 kyr) recurrence times between events (per segment), which indicate that earthquakes are not perfectly periodic (as also shown by a COV on recurrence of about 0.5). However, most agreed that although a Poisson (time-independent) process cannot be ruled out considering the earthquake timing data, a process of stress renewal, where the time to the next earthquake is linked to the time since the last, is likely more appropriate for the WFZ.

Table 2. *Currently proposed time-independent and time-dependent behavior weights and weights for recurrence interval models for the five central segments of the Wasatch fault zone.*

- Time independent (0.3) Recurrence intervals Weight
    - Composite N-in-T 0.5
    - Segment-specific N-in-T 0.5

- Time dependent (0.7)
    - Brigham City segment (BCS)
        - Closed mean 0.33
        - Composite closed mean 0.33
        - N-in-T 0.34
    - Weber, Salt Lake City, and Provo segments
        - Closed mean (per segment) 0.5
        - Composite closed mean 0.5
    - Nephi segment (NS)
        - Composite closed mean 0.5
        - Closed mean 0.25
        - N-in-T 0.25

Open mean RIs for the segments are based on an N-in-T calculation (number of events N occurring in time window T). These values range from about 1.1 kyr to 1.5 kyr depending upon the segment considered. The shorter mean RI reflects the short (late Holocene to present) time window (and possibility of clustered events) on the Nephi segment. In contrast, the Brigham City segment has the longest mean recurrence because of the long elapsed time since the segment's most recent earthquake, which is included in the N-in-T calculation. Chris presented and discussed weights for the open mean recurrence estimates, which will be used in the time-independent branch.

Closed mean (inter-event) RIs for the central WFZ segments range from about 0.9 kyr to 1.3 kyr depending on the segment considered. The closed mean values per segment, plus a composite mean recurrence for the central WFZ will be used in time-dependent earthquake probabilities for the five central WFZ segments. The Brigham City and Nephi segments will also include open mean recurrence, based on an N-in-T calculation per segment. The working group discussed weights for the closed mean recurrence estimates, which will be used in the time-dependent branch.

Chris presented revised displacement per event estimates, which reflect a more reproducible calculation method. The average vertical displacement is based on a least-squares best-fit half ellipse that is fit to the trench site displacement observations. The best-fit ellipse is that which minimizes the error (sum of squared deviations from the field observations) from a range of ellipses with varying shapes and heights. The best-fit ellipse method reasonably approximates average displacements as measured in historical normal-faulting earthquakes.

Vertical slip rate estimates for the central WFZ include (1) closed slip rates based on the total (or average) displacement to occur in a specific inter-event time window (or average closed recurrence interval), (2) open slip rates, which include the open intervals from the oldest event to its maximum-limiting age constraint and from the youngest event to the present, and (3) long-term slip rates, generally based on displaced Lake Bonneville sediments and shorelines. The working group discussed the pros and cons for each of these measurement types (and values for each segment), as well as composite slip rates for the central WFZ to be consistent with the recurrence intervals used. The subgroup presented a revised strawman model for slip rates:

- Brigham City and Nephi segments — Weight
  - Composite closed (paleoseismic) slip rate — 0.3
  - Mean (~composite) long-term slip rate — 0.3
  - Closed (paleoseismic) slip rate per segment — 0.2
  - Open paleoseismic slip rate (per segment) — 0.2

- Weber, Salt Lake City, and Provo segments — Weight
  - Composite closed (paleoseismic) slip rate — 0.35
  - Closed (paleoseismic) slip rate per segment — 0.35
  - Mean (~composite) long-term slip rate — 0.3

The working group also discussed characteristic magnitude ($\mathbf{M}_{char}$) estimates for the central WFZ (category A) and other faults (category B/C). The consensus was to use the final strawman developed by Paleoseismology Subgroup:

- Category A faults (2+ paleoseismic sites) — Weight
  - Hanks and Kanamori (1979) – M_o — 0.3
  - Stirling and others (2002) – SRL (censored instrumental) — 0.3
  - Wells and Coppersmith (1994) – SRL (all fault types) — 0.2
  - Wells and Coppersmith (1994) – A (all fault types) — 0.2

- Category B/C faults (all others) — Weight
  - Stirling and others (2002) – SRL (censored instrumental) — 0.4
  - Wells and Coppersmith (1994) – SRL (all fault types) — 0.2
  - Wells and Coppersmith (1994) – A (all fault types) — 0.2
  - Anderson and others (1996) – slip rate and SRL — 0.2

  (M_0 – seismic moment, SRL – surface rupture length, A – area)

However, for the central WFZ, the working group also discussed possible modeling issues related to using the Wells and Coppersmith (1994) regressions (for SRL and A), which predict less moment release per earthquake than the Hanks and Kanamori (1979) and Stirling and others (2002) regressions. Depending on the modeling results, additional discussion of the M regressions used or the weights assigned may be necessary.

The Wasatch Fault Zone End Segments
Slip Rate and Length — Model Distributions and Weights

Mike Hylland reviewed the available paleoseismic data (table 3) for the WFZ end segments (north = Malad City, Clarkston Mountain, Collinston; south = Levan, Fayette). He then summarized the strawman source parameters for the five segments (table 4). The principal change in this iteration of the strawman parameters from previous versions, was the inclusion of length and slip-rate (SR) distributions for the segments that reflect 5th, 50th, and 95th percentiles.

Discussion accompanying Mike's presentation included the decision to treat the WFZ end segments as 50% unsegmented and 50% segmented. For the unsegmented model on the three northern segments, it is proposed to float a 60 km-long boxcar with a minimum magnitude of 6.75 $\pm$ 0.25, a maximum magnitude commensurate with a 60 km surface rupture length, and a magnitude distribution slope of b = 0.8. The unsegmented model for the two southern end segments will utilize a 46 km-long boxcar again with a minimum magnitude of 6.75 $\pm$ 0.25, a maximum magnitude commensurate with a 46 km surface rupture length, and a magnitude distribution slope of b = 0.8.

Table 3. *Summary of earthquake parameters for the Wasatch fault zone end segments.*

Segment	***MRE Timing***	***Displacement/ Surface Offset (m)***	***Time Interval (kyr)***	***Estimated 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)*
*** Utah Quaternary Fault Parameters Working Group (UQFPWG; Lund, 2005).*

Table 4. *Wasatch fault zone end segments strawman model parameters.*

Segment	Length (km)	Length Uncertainty (km)	Length Range (km)	Length Distribution (5th, 50th, 95th) (0.2–0.6–0.2)	Slip Rate Consensus Range (mm/yr)	Slip Rate Distri (5th, 50th, 95 (0.2–0.6–0.
Malad City	40	+/-6	34 – 46	34 – 40 – 46	0.01 – 0.1	0.01 – 0.05 –
Clarkston Mountain	19	+/-6	13 – 25	13 – 19 – 25	0.01 – 0.1	0.01 – 0.05 –
Collinston	30	+/-6	24 – 36	24 – 30 – 36	0.01 – 0.1	0.01 – 0.05 –
Levan	32	+/-6	26 – 38	–	0.1 – 0.6	0.1 – 0.3 – (
Levan (mapped Holocene rupture)	25	+/-6	19 – 31	–	–	–
Levan (incl. faults in L-F step-over)	37	+/-6	31 – 43	–	–	–
Levan – ***Length range to consider***	–	–	19 – 43	19 – 31 – 43	–	–
Fayette	22	+/-6	16[1] – 28	17.5 – 22 – 28	0.01 – 0.1	0.01 – 0.05 –
Levan + Fayette (multi-segment rupture)[2]	46[3]	+/-6	40 – 52	40 – 46 – 52	–	–

[1] *Use default minimum length to generate M 6.5 earthquake (17.5 km).*
[2] *WGUEP recommends giving 0.5 weight to this model.*
[3] *End-to-end combined length; avoids double-counting length of overlap that would occur from simply summing individual segment lengths.*

Oquirrh-Great Salt Lake Fault Zone Revisited

Susan Olig reviewed the current segmentation model for the Oquirrh-Great Salt Lake fault zone (O-GSLFZ) (figure 2) and the timing information available for the most recent surface-faulting earthquake on each of the proposed O-GSLFZ segments (table 5).

O-GSLFZ SEGMENTS
Rozelle (RZ) – 25 km
Promontory (PY) – 25 km
Fremont Is. (FI) – 25 km
Antelope Is. (AI) – 35 km
No. Oquirrh (NO) – 30 km
So. Oquirrh (SO) – 31 km
Topliff Hills (TH) – 26 km
East Tintic (ET) – 35 km

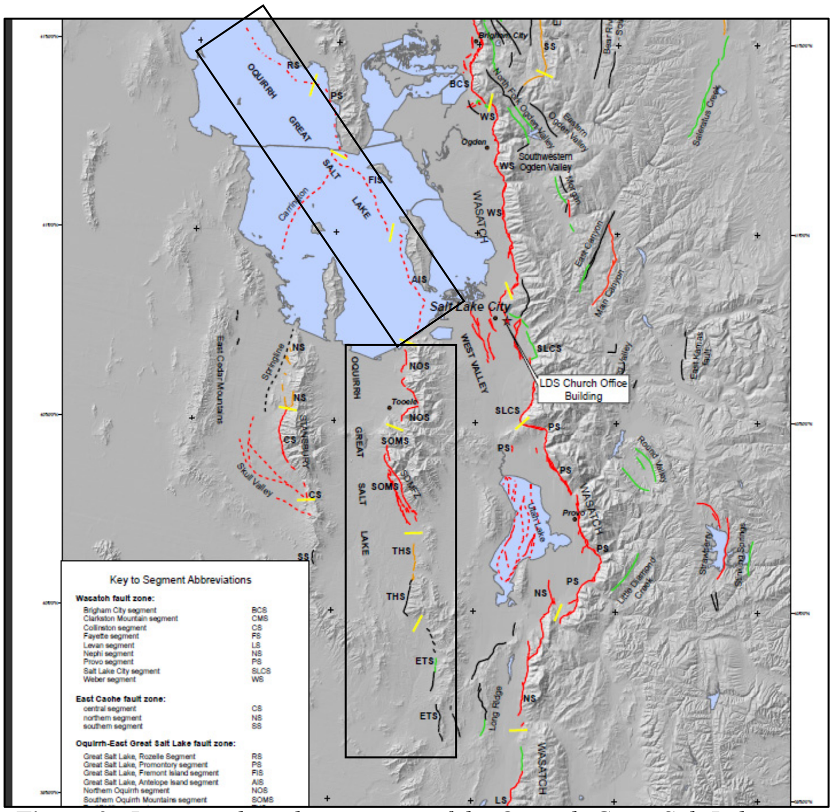


Figure 2. *Boxes enclose the segments of the Oquirrh-Great Salt Lake fault zone.*

Table 5. *Ages of youngest surface-faulting along segments of the Oquirrh-Great Salt Lake fault zone.*

	Fault Segment	Youngest Event	Penultimate Event	Older Events?[3]
Great Salt Lake fault[2]	Rozelle (RZ)	Holocene?	?[3]	?[3]
	Promontory (PY)	Holocene?	?[3]	?[3]
	Fremont Island (FI)	3,150 (+240, -210)	6,410 (+210, -210)	< 11,430 (+610, -450)
	Antelope Island (AI)	590 (+200, -240)	6,170 (+240, -230)	9,900 (+250, -300)
	Northern Oquirrh (NO)[4]	6330 (4960 to 7650)	20,300 - 26,400	> > 33,000
	Southern Oquirrh (SO)[5]	1,300 to **4,830**[6]	20 to 50 ka[6]	shortly after 42 ± 8; shortly after 75 ± 10 ka; ca. 92 ± 14 ka[6]
	Topliff Hills (TH)	> 15,000[7] or < 15,000[8]	?[3]	?[3]
	East Tintic (ET)	> > 15,000 (middle to late Pleistocene)[9]	?[3]	?[3]

Note: Footnotes for table 5 not provided in Susan's PowerPoint presentation.

Susan then presented revised strawman rupture models for the O-GSLFZ (table 6) and supporting evidence for her segmentation model.

Table 6. *Proposed rupture models and weights for the Oquirrh-Great Salt Lake fault zone.*

Rupture Scenarios[1,2]		Old Strawman 2 Weights (Meeting #6)	New Strawman 3 Proposed Weights
1	RZ, PY, *FI, AI,* NO+SO, TH, ET	0.25	0.15
2	RZ, PY, *FI, AI,* NO, SO, TH, ET	0.4	0.5 (or 0.45?)
3	RZ, PY, FI+AI, NO, SO, TH, ET	0.1	0.1
4	RZ, PY, *FI, AI,* NO, SO+TH, ET	0.1	0.1
5	Unsegmented (floating)	0.15	0.15 (or 0.2?)

[1] *Rupture scenario abbreviations defined in table 5.*
[2] *Red italics indicates time-dependent model considered.*

Supporting data for each of the proposed segmentation models is as follows:

1. RZ, PY, FI, AI, NO+SO, TH, ET
    - Ages of penultimate event (PE) and antepenultimate event (APE) overlap for NO and SO (but uncertainties are large).
    - Displacements per event are very large for both NO (2.2-2.7 m) and SO (1.3-2.2 m) given their individual lengths of only 21 and 24 km, respectively.
    - Late Quaternary displacement profiles (from scarp profile data) do not taper but stay large near the NO-SO segment boundary.
    - NO and SO have similar late Quaternary slip rates of 0.1-0.2 mm/yr.

2. RZ, PY, FI, AI, NO, SO, TH, ET
    - Gaps and step-overs of late Quaternary scarps and ranges.
    - Age of most recent earthquakes (MREs) different (for those that are reasonably constrained).
    - Basin geometry (except SO & TH and FI & AI).

3. RZ, PY, FI+AI, NO, SO, TH, ET
    - Age of PEs of FI and AI overlap.
    - Similar slip rates for FI and AI.
    - Traces overlap and geometrical step-over is small.

- Large displacements per event for AI for length of 32 km.

4. RZ, PY, FI, AI, NO, SO+TH, ET
   - Basin geometry (continuous and deepest at SO-TH boundary).
   - Large displacements per event for SO.
   - Permissible that ages of events overlap (data poor on TH).

5. Unsegmented
   - Large uncertainties (particularly for RZ, PY, TH, ET).
   - Accounts for scenarios with weight < 0.1.

6. Why AI+NO weight is considered < 0.1.
   - Large difference between the rates of activity on the AI and NO (rates on AI are 2 to 4 times higher than NO).
   - The major right-step and change in strike between AI and NO fault traces.
   - Basin and range geometry.
   - Large uncertainty in age of MRE on NO (6330 yr, 4960 yr to 7650 yr) argues against the significance of the overlap between this age and that of the PE on AI (6170 yr, + 240, -230); (sum of the 2-sigma uncertainty limits is (7650 yr - 4960 yr) + (240 yr + 230 yr) = 3160 years, which is 75% (56% to 113%) of the estimated average single-segment recurrence interval for the southern Great Salt Lake fault zone of 4200 yr +/- 1400 years).

Considerable discussion ensued within the working group regarding both the rupture models and the weights assigned to them. In the end, although some would have liked to see a rupture scenario that included an AI+NO multisegment rupture, Susan's rupture model was adopted by the working group. However, based on the discussion, the rupture model weights were adjusted as shown in table 7.

Susan then presented weighted recurrence intervals for the Great Salt Lake fault zone segments and weighted vertical slip rates for the segments of the Oquirrh fault zone, a recommendation for COV, parameters for the unsegmented model, and strawman weights for the time-dependent analysis of the fault.

Rates

- Use UQFPWG (Lund, 2005) recurrence intervals for GSLFZ:
  1,800 yrs (0.2)
  4,200 yrs (0.6)
  6,600 yrs (0.2)
- Use UQFPWG (Lund, 2005) (vertical) slip rates for NO and SO:
  0.05 mm/yr (0.3)
  0.15 mm/yr (0.4)
  0.3 mm/yr (0.3)
- Use lower rates for TH and ET (based on scarp-profile data):
  0.05 mm/yr (0.3)
  0.1 mm/yr (0.4)
  0.2 mm/yr (0.3)

Other parameters

- COV: Use WFZ COVs.
- Unsegmented model: approach generally consistent with WFZ – float **M** 6.75 to M_{char} (using average segment length times 3) ruptures; b = 0.8.
- Strawman weight on time-dependent: 50/50.

Table 7. *Final rupture models and weights for the Oquirrh-Great Salt Lake fault zone.*

Rupture Scenarios[1,2]		**New Strawman 4 Weights**
1	RZ, PY, *FI, AI,* NO+SO, TH, ET	0.15
2	RZ, PY, *FI, AI,* NO, SO, TH, ET	0.4
3	RZ, PY, FI+AI, NO, SO, TH, ET	0.15
4	RZ, PY, *FI, AI,* NO, SO+TH, ET	0.1
5	Unsegmented (floating) (3 times average segment length)	0.2

[1] *Rupture scenario abbreviations defined in table 5.*
[2] *Red italics indicates time-dependent model considered.*

Other Fault Parameters

Bill Lund reviewed the current status of the Wasatch Front Region (WFR) "Other Fault" database. Revisions since WGUEP Meeting #6 include:

- Revised dip angles for the Hansel Valley (35-50-90 deg) and Joes Valley (50-75-85 deg) faults based on Mike Hylland's review of antithetic fault pairs in the WFR.
- A rupture length for the Joes Valley fault of 37 km, which reflects the evidence for the surface rupture length of latest Quaternary (< 15 kyr) movement on the fault.
- A revised rupture depth for the Joes Valley fault of 3 km, based on seismic-line evidence which shows that the fault does not displace the top of the Navajo Sandstone (at least within the resolution of the seismic profiles).
- A revised Probability of Activity for the Joes Valley fault of 0.5, based on the shallow rupture depth.
- A revised slip-rate distribution and weights for the Western Bear Lake fault of 0.1 (0.2), 0.5 (0.6), 0.8 (0.2).
- Removal of the Great Salt Lake, Oquirrh, and East Canyon faults from the "Other Fault" database.

Final Recurrence Models and Weights

Ivan presented the final recurrence models for faults in the WGUEP study area as follows:

- Wasatch and Oquirrh-Great Salt Lake Fault Zones
  - 0.9 Maximum Magnitude (M_{min} 6.75)
  - 0.1 Truncated Exponential (M_{min} 6.75)
- Other Faults
  - 0.8 Maximum Magnitude (M_{min} 6.75)
  - 0.2 Truncated Exponential (M_{min} 6.75)
- Background Seismicity (also includes earthquakes that may be on faults)
  - 1.0 Truncated Exponential (**M** 5.0 to M_{max} 7.0)
- For faults that have $M_{max} < 6.75$, only the Maximum Magnitude model will be used.

Antithetic Fault Parameters

Mike Hylland addressed the question of how antithetic fault pairs should be modeled, since depending on fault dip and distance between faults, one fault of an antithetic pair will likely truncate the other within seismogenic depths. The principal question for modeling is how to determine which fault is the master fault and which is the subsidiary (truncated) fault.

The Basin and Range Province Earthquake Working Group II (BRPEWGII) (Lund, 2012) addressed the antithetic fault pair question as it relates to the National Seismic Hazard Maps, and made the following recommendations to the U.S. Geological Survey National Seismic Hazard Mapping Program.

- Explore using metrics (such as length, topographic relief, overlap) to guide selection of master and subsidiary faults.
  - Evaluate dataset for overlapping relations (comparative indicator of controlling structure) to select master fault based on length (proxy for fault maturity).
  - Evaluate using aspect ratio (length/width) for individual fault pairs
  - Where data allow, structural throw should be used rather than topographic relief (proxy for long-term slip rate).
  - Evaluate using length times throw as a parameter for selecting master fault.
- Subsurface data (e.g., seismic reflection) should be used to guide master fault selection, where available.
- Where available data do not give a clear indication of master versus subsidiary faults, model both alternatives using a logic tree approach.

Mike evaluated fault metrics for six antithetic fault pairs in the WGUEP study area, including length, percent overlap, minimum and average topographic relief, and length times relief. Results of the evaluation allowed Mike to identify three master faults based on fault metrics. Two other master faults could only be identified using available subsurface data, and one fault pair required using a logic tree approach. Results of the evaluation are summarized in table 8.

Table 8. *Master/subsidiary fault classification for antithetic fault pairs in the WGUEP study area.*

Fault	Length	Overlap	Relief	Length X Relief	Classification
West Valley fault zone	S	S	S	S	**S**
Salt Lake City segment	M	M	M	M	**M**
Utah Lake faults	S	S	S	S	**S**
Provo segment	M	M	M	M	**M**
Hansel Valley–Hansel Mtns (east side) faults	[M]	[M]	M	M	**M** (0.25)
North Promontory fault	[S]	[S]	S	S	**M**[1] (0.75)
West Cache fault	S	S	S	S	**S**
East Cache fault (incl. James Peak fault)	M	M	M	M	**M**
Western Bear Lake fault	S	[S]	M	M	**S**
Eastern Bear Lake fault	M	[M]	S	S	**M**[2]
Joes Valley faults (west side)	—	—	M	M	**S**
Joes Valley faults (east side)	—	—	S	S	**M**[3]

M, master fault; S, subsidiary fault.
Brackets indicate <10% difference in parameter values.
[1] *Likelihood for master fault based on regional pattern of half-graben structure.*
[2] *Master fault based on interpreted seismic reflection data (Evans, 1991).*
[3] *Master fault based on interpreted seismic reflection data (Anderson, 2008); neither fault penetrates deeper than about 3.4 km.*

Based on his evaluation, Mike assigned preliminary 5th and 95th percentile dip distributions with weights for each fault pair, and assigned preliminary weights for coseismic versus independent behavior for the faults (table 9).

Table 9. *Strawman parameters for antithetic fault pairs in the WGUEP study region.*

Fault	**Classification**[1]	**Dip**[2] **(degrees) (5th, 50th, 95th) (0.3–0.4–0.3)**	**Independent vs. Coseismic (vs. non-seismogenic)**[3]
West Valley fault zone	S	35–50–65	0.55, 0.45
Salt Lake City segment	M	35–50–65	0.55, 0.45
Utah Lake faults	S	35–50–65	0.4, 0.3 (0.3)[4]
Provo segment	M	35–50–65	0.55, 0.45
Hansel Valley + Hansel Mtns (east side) faults	M (0.25)	35–50–90[5]	0.55, 0.45
North Promontory fault	M (0.75)	35–50–65	0.55, 0.45
West Cache fault	S	35–50–65	0.7, 0.3[6]
East Cache fault + James Peak fault	M	35–50–65	0.8, 0.2[6]
Western Bear Lake fault	S	35–50–65	0.55, 0.45
Eastern Bear Lake fault	M	35–50–65	0.55, 0.45
Joes Valley faults (west side)	S	55–70–85[7]	0.3, 0.4 (0.3)[8]
Joes Valley faults (east side)	M	55–70–85[7]	0.4, 0.3 (0.3)[8]

[1] *M, master fault; S, subsidiary fault (truncated at depth by master fault) with weights as appropriate.*
[2] *Default WGUEP dip distribution (50° ± 15°) except where noted.*
[3] *Preliminary WGUEP recommended range except where noted.*

[4] *Potential non-seismogenic character of the fault weighted 0.3 after S. Olig (p[a] = 0.7; written communication).*
[5] *Preliminary WGUEP recommended range.*
[6] *Higher weights for independent behavior relative to other fault pairs based on greater average separation distance between the West and East Cache fault; higher weight for East Cache fault being independent relative to West Cache fault based on higher likelihood of East Cache fault being the master fault.*
[7] *Range based on interpreted seismic reflection data (Anderson, 2008).*
[8] *Potential non-seismogenic character of the faults weighted 0.3 after S. Olig (p[a] = 0.7; written communication); higher weight for east side fault being independent relative to west side fault based on higher likelihood of east side fault being the master fault.*

In the discussion following Mike's presentation, Walter noted that in our region, master faults are always on the east side (west dipping) of Basin and Range valleys. For that reason, he favors the North Promontory fault as the master fault in the North Promontory/Hansel Valley fault pair. Jim Pechmann pointed out that the focal mechanism for the 1934 Hansel Valley earthquake was strike slip, and may not represent a characteristic earthquake on the Hansel Valley fault – the northern part of which showed no surface rupture in the 1934 event. Discussion then turned to weighting of independent versus coseismic behavior of the faults. The following values seemed to gain general approval from the working group.

West Valley fault Zone	50/50
Utah Lake faults	50/50
Hansel Valley fault	60/40
West Cache fault zone	Independent (100)
East Cache fault zone	Independent (100)
West Bear Lake fault	50/50

Discussion continued regarding the Joes Valley fault zone. The working group agreed that because of the very small separation distance between the graben-bounding faults (~2-3 km), the Joes Valley fault zone should be treated as a single system rather than individual faults. Discussion then turned to the seismogenic nature of the fault zone and, given the apparent shallow rupture depth (~3 km), whether the faults are seismogenic at all. Available U.S. Bureau of Reclamation seismic-reflection lines show that the Joes Valley faults become listric and sole into the Carmel Formation, which contains gypsum/anhydrite and likely forms a regional detachment surface. The seismic lines do not show the faults penetrating the upper contact of the underlying Navajo Sandstone, which appears as a very strong reflector on the seismic profiles. Concern was expressed that the resolution of the seismic lines may be insufficient to resolve displacements of only a few tens of meters, so it cannot be conclusively stated that the faults do not penetrate the Navajo and continue to seismogenic depth. However, if the bedrock units below the Carmel are displaced, the amount of displacement is small and significantly less than the displacements observed within the Joes Valley graben at the surface (~ 300 m). The working group recommended assigning the Joes Valley fault zone a probability of activity of 0.4 (40% seismogenic, 60% non-seismogenic), and including a branch on the earthquake source logic tree for a fault plane that penetrates to full seismogenic depth (15 $\pm$ 3 km), but assigning that branch a low weight.

Maximum Earthquake Focal Depths in the WGUEP Wasatch Front Region

Jim Pechmann reported on his investigation of WGUEP earthquake focal depths and whether the WGUEP seismic source model should incorporate different seismogenic depths for faults in different parts (physiographic provinces) of the WGUEP study region. Jim limited his investigation to earthquakes that met both of the following criteria:

- Epicentral distance to the nearest station less than or equal to the focal depth or 5 km, whichever was larger.
- Standard vertical hypocentral error of 2 km or less, as calculated by the location

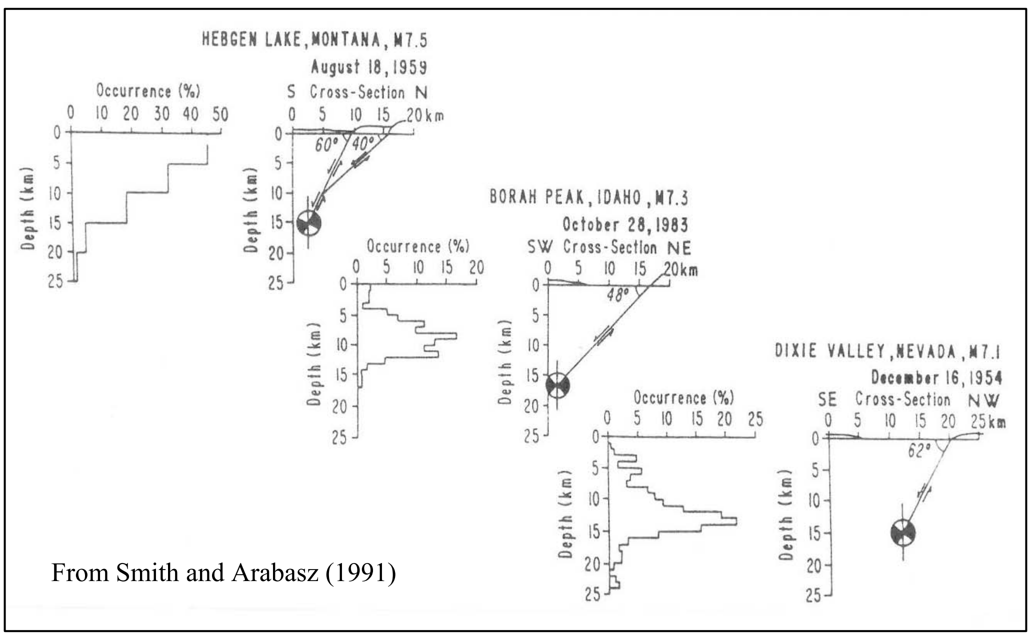
program.

Jim identified 2523 earthquakes in the WGUEP study area that met the two quality criteria. The events are poorly distributed across the study area, with the majority in a comparatively narrow, north-south-trending band along either side of the WFZ. There were few good quality events in the western (Basin and Range) portion of the study area. Jim's analysis showed that the focal depths systematically increased east of about 111° 50' west longitude (table 10). Jim noted that 111° 50' west longitude is about the location of the WFZ in the WGUEP study area.

Table 10. *Focal depth percentiles for the WGUEP study region.*

	West of -111° 50'	East of -111° 50'	Entire Region
Number of events	1505	1018	2523
90th percentile depth	11.1 km	16.2 km	14.1 km
95th percentile depth	12.4 km	18.0 km	16.0 km

Jim went on to note and Walter concurred that although there is a systematic 5 to 6 km increase in the depth of earthquake hypocenters east of the WFZ, for the largest historic earthquakes in the Intermountain West, the hypocentral depths have consistently been about 15 km (figure 3), and those are the data we should use for this study.



From Smith and Arabasz (1991)

Figure 3. *Hypocentral depths of large Intermountain West normal fault earthquakes.*

Based on Jim's analysis, the working group determined to adjust the seismogenic depth for the WGUEP earthquake model from 15 $\pm$ 2 km to 15 $\pm$ 3 km, and to apply different weights east and west of the WFZ as follows:

East of the WFZ: 12 (0.1), 15 (0.7), 18 (0.2)
West of the WFZ: 12 (0.2), 15 (0.7), 18 (0.1)

Smoothing of Background Seismicity

Following the discussion on spatial smoothing at WGUEP Meeting #6, Ivan stated that he would discuss that issue and also the appropriate smoothing kernel to use with Bob Youngs (AMEC Geomatrix Consultants, Inc.). Ivan reported at this meeting that the WGUEP would use some form of Gaussian smoothing, starting with a 10 km kernel (50 km is too coarse for a regional study), and would go to adaptive smoothing as necessary. Mark Petersen states that the USGS was looking into adaptive smoothing as was done for the Central and Eastern United States Seismic Source Characterization for Nuclear Facilities project. Ivan and Mark agreed that the USGS would take responsibility for handling the background earthquake forecast.

Evaluation of Geodetic Models in Northern California

Mark Petersen showed a series of five slides. The first two compared California geologic slip-rate data for various faults with four geodetic slip models (Zeng, G1, NeoKinema, and bounded). There was reasonable correlation between the geologic slip data and the bounded geodetic model. The other models systematically under predicted the geologic slip for the San Andreas from the central California creeping section to the San Bernardino Mountain segment.

Mark next showed a figure depicting the largest Quaternary faults in the Wasatch Front region. Six boxes, each representing one of the six Holocene-active segments of the WFZ, extending 50 km east and 100 km west of the WFZ were plotted on the figure. Each box was assigned an average geodetic slip rate that corresponded to the total GPS vector differences east and west of the WFZ projected to a 50 degree fault plane. With the exception of the Weber segment, the slip rates become progressively larger from north to south, with values for the Nephi and Levan segments a factor of two or greater than those for the other four segments. Mark's fourth slide showed GPS velocity profiles for each of the 150-km-wide segment boxes, and the average GPS velocities east and west of the WFZ for each segment. Velocities west of the WFZ were all larger (in some cases by more than a factor of 2) than velocities east of the WFZ. The fifth slide showed three east-west GPS velocity profiles that correspond to (1) the entire north-south length of the six central WFZ segments, (2) the Brigham City, Weber, and Salt Lake City segments, and (3) the Provo, Nephi, and Levan segments. The profiles again showed that geodetic extension is systematically higher west of the WFZ than to the east, in all cases by greater than a factor of two.

Uniform California Earthquake Rupture Forecast, Version 3
Evaluation of Geodetic Models in California

Ivan and Dave recently attended the 2012 Northern California Earthquake Hazards Workshop. Kaj Johnson, University of Michigan, made a presentation on the Uniform California Earthquake Rupture Forecast, version 3 (UCERF3) geodetic model. The UCERF3 model is based on a single block model by Dawson and Weldon that was not reviewed. Ivan's observations/notes on the workshop were as follows:

- Systematic misfits: geodetic rates were too high along northern San Andreas and too low along southern San Andreas. Match was good along central San Andreas (San Francisco Bay area).
- High bias to predicted geodetic slip rates for faults with low geologic slip rates – Tim Dawson
- Expect bias to be opposite – Ray Weldon
- Possible explanations
    - Geologic rates overestimated?
    - Deformation models inadequate?

- Missing postseismic deformation?
- Temporal variation in velocity field?
- Experiencing some time-dependent mantle flow?
- Internal block deformation?

- Reduce block size to improve match?
- Effect of locking depth is small.
- How to evaluate block model assumption?
- None of the models fit the data – Kaj Johnson
- Pushing rigid block models too far? – Paul Segall
- Choice of block geometry subjective – Wayne Thatcher
- Don't rely on a single model – Kaj Johnson
- Careful model validations are needed – Kaj Johnson

It is Ivan and Dave's impression from the workshop that the California geodetic model is not ready to be applied to individual faults, and since the geodetic model for the Wasatch Front Region is similarly limited, they see no reason to attempt to apply the Wasatch Front data to individual faults in the WGUEP study area. Dave stated that at best, the Wasatch Front geodetic data should be used as a regional constraint on slip.

Probability Calculations and Input Sensitivities

Patricia Thomas reported on her preliminary probability calculations and input sensitivities for the five central segments of the WFZ (Brigham City, Weber, Salt Lake City, Provo, and Nephi). Because the results are preliminary and subject to change, neither the probabilities nor the input values used to calculate them are reported here. Patricia's presentation addressed the following four elements for the WFZ central segments:

- M_{char} distributions
- Moment balanced RIs
- Poisson probabilities
- Brownian Passage Time (BPT) probabilities

M_{char} Distributions

Patricia presented Weighted Mean M_{char}, 5th Percentile M_{char}, and 95th Percentile M_{char} magnitudes for a single segment model of the five central WFZ segments. Four M_{char} relations (SRL, A, SRL-c, and M_o) were used to calculate the mean values; inputs for the relations (length, dip, seismogenic thickness, and average displacement) were as specified by the Paleoseismology Subgroup (see previous WGUEP meeting summaries at http://geology.utah.gov/ghp/workgroups/wguep.htm). Patricia showed plots of the weighted mean M_{char} distribution and of the contribution each of the four M_{char} relations made to the weighted mean M_{char} for each of the five central WFZ segments.

Moment Balanced RIs

Patricia reviewed the WGUEP recurrence models (Truncated Exponential and Maximum Magnitude) and the two rupture source rates (A-priori [data driven] and moment balanced [calculated from modeled slip rates]) used with the models to determine RIs. Using the Brigham City segment as an example, Patricia showed a graph of moment balanced rates versus A-priori rates, and follow up graphs showing the range of moment balanced RIs calculated for the segment using each of the four M_{char} relations. Depending on the relation used the range in RIs varied by more than a factor of three. Patricia then presented a table of moment balanced Weighted Mean RIs, 5th Percentile RIs, and 95th Percentile RIs for a WFZ single segment model for the five central WFZ segments. The values were generally lower than A-priori RIs determined from paleoseismic trenching investigations on those segments. Two follow up tables demonstrated the sensitivity of the moment-balanced RIs to M_{char} and slip-rate relations. Graphs of the results showed that RIs calculated using the M_{char} relations for SRL and A were consistently lower than A-priori rates. Conversely, graphs showing RIs calculated using the M_0 and SRL-c M_{char} relations compared well with A-priori rates, raising the question—*Should we continue to use the SRL and A M_{char} relations in the WGUEP forecast model if they consistently underestimate both M_{max} and RI?* A final table compared weighted mean slip rates determined from A-priori rupture rates with weighted mean slip rates determined from moment-balanced rupture rates for the five central WFZ segments. The values compared well for the Brigham City and Weber segments, but varied by as much as 0.4 for the other three segments.

Probability Calculations

Patricia reviewed the probability inputs for the WFZ model:

- 10% Poisson (rupture rates, M_{char} distribution)
- 90% Time Dependent (rupture rates, M_{char} distribution, MRE, COV)
  - Rupture rates: moment-balanced versus A-Priori
    (A-priori: weighting for Closed Mean, N Event in T Time; Composite Mean RIs based on segment and Poisson / Time Dependent)
  - COVs: 0.3 (0.2), 0.5 (0.6), 0.7 (0.2)

Patricia then presented a table showing the probability of an M > 6.7 earthquake in 50 years for a Wasatch fault single segment model using A-priori rates (1/RIs). The table included both Poisson and BPT (COVs of 0.3, 0.5, and 0.7) probabilities for each of the five central WFZ segments and for the five segments combined. The table was followed by a series of Tornado plots showing the sensitivity of the Poisson probabilities for each of the five WFZ segments to the model input parameters. Patricia summarized the sensitivity of Poisson probabilities using A-priori rates as follows:

- Poisson probabilities = f (Rupture rates, $P[\mathbf{M} > \mathbf{M}_T]$).
- M_{char} relation has greatest impact on $P(\mathbf{M} > \mathbf{M}_T)$.
- Rupture length, dip, seismogenic thickness and average displacement have lesser impact on $P(\mathbf{M} > \mathbf{M}_T)$.
- Distribution of A-priori rupture rates has smaller impact on Poisson probabilities than M_{char} relations.

Patricia then presented a table showing the probability of an M > 6.7 earthquake in 50 years for a Wasatch single segment model using moment-balanced rates. The table included both Poisson and BPT (COVs of 0.3, 0.5, and 0.7) probabilities for each of the five central WFZ segments and for the five segments combined. The table was followed by a series of Tornado plots showing the sensitivity of the Poisson probabilities using moment-balanced rates for each of the five WFZ segments to the model input parameters. Patricia summarized the sensitivity of Poisson probabilities using moment-balanced rates as follows:

- Poisson probabilities = f (Rupture rates, $P[\mathbf{M} > \mathbf{M}_T]$).
- Rupture rates balance long-term segment moment rate with mean moment of M_{char}.
- Slip rate, length, dip, and seismogenic thickness impact long-term segment moment rate.
- M_{char} relation impacts both rupture rate and $P(\mathbf{M} > \mathbf{M}_T)$.
    - Increased M_{char} increases $P(\mathbf{M} > \mathbf{M}_T)$, but reduces rupture rate.
- Rupture length, dip, seismogenic thickness and average displacement have lesser impact on $P(\mathbf{M} > \mathbf{M}_T)$.

Finally, Patricia presented a WFZ single segment model for the probability of a M > 6.7 earthquake in 50 years based on 80% time dependent and 20% Poisson models for both A-priori and moment-balanced rates. Her first table showed the combined A-priori and moment-balanced probabilities for each of the five central WFZ segments and the five segments as a whole, the second table showed the contribution to the combined probabilities from the Poisson and time dependent models for each segment and the segments as a whole.

Patricia finished her presentation by summarizing the remaining inputs required to complete the WGUEP earthquake forecast:

- Multisegment rupture rates
- WFZ unsegmented model slip rates
- Background seismicity
- O-GSLFZ input parameters
- Antithetic fault inputs
- Weighting on moment balanced versus A-priori rates
- Weighting on time-dependent and Poisson

REFERENCES

Presenters did not provide complete citations for the references given in their presentations and reported in these minutes.

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, 109 p., available at http://ugspub.nr.utah.gov/publications/bulletins/B-134.pdf.

Lund, W.R., editor, 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.

NEXT MEETING

The next WGUEP meeting is scheduled for August 8-9, 2012, at the Utah Department of Natural Resources Building (1594 West North Temple, Salt Lake City, Utah).

ATTACHMENT 1

Attendance

Working Group on Utah Earthquake Probabilities
Meeting #7

Walter Arabasz, UUSS
Tony Crone, USGS
Chris DuRoss, UGS
Mike Hylland, UGS
Nico Luco, USGS
Bill Lund, UGS, Coordinator
Susan Olig, URS Corporation
James Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
Dave Schwartz, USGS
Bob Smith, UUGG
Patricia Thomas, URS Corporation
Ivan Wong, URS Corporation, Chair

Others presenting or assisting the Working Group
Steve Bowman, UGS Liaison to WGUEP

ATTACHMENT 2
AGENDA
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #7
Thursday/Friday, 16 & 17 February 2012
Utah Department of Natural Resources Building, Room 1040-1050 (1st floor)
1594 West North Temple, Salt Lake City

<u>Thursday, 16 February</u>

8:00 – 8:30	Continental Breakfast	
8:30 – 8:45	Overview of Agenda and Review of Last Meeting's To Do List	Ivan
8:45 – 9:30	Update on Consensus Wasatch Front Earthquake Catalog	Walter/Jim
9:30 – 10:00	Multi-Segment Ruptures on Normal Faults	David
10:00 – 10:15	Break	
10:15 – 11:15	Wasatch Central Segment Final RIs, Time-Dependent/Time Independent Weights, M_{max}	Chris/Nico
11:15 – 11:45	Wasatch End Segments Final Slip Rates and M_{max}	Mike/Chris
11:45 – 12:30	Lunch	
12:30 – 1:30	O-GSL Parameters	Susan/Jim
1:30 – 2:15	Other Faults Final Parameters	Bill/Susan
2:15 – 2:45	Final Recurrence Models and Weights	Ivan
2:45 – 3:15	Final Seismogenic Thicknesses	Jim
3:15 – 3:30	Break	
3:30 – 4:15	Update on Geodetic Analysis	Jim/Mark/ David
4:15 – 5:00	Evaluation of Geodetic Models in Northern California	Ivan

<u>Friday, 17 February</u>

8:00 – 8:30	Continental Breakfast	
8:30 – 9:15	Background Seismicity Parameters	Mark/Ivan
9:15 – 10:00	Antithetic Fault Parameters	Mike
10:00 – 10:15	Break	
10:15 – 12:00	Preliminary Forecast	Patricia
12:00 – 1:00	Lunch	
1:00 – 2:00	Path Forward	All
2:00	Adjourn	

<u>WGUEP Members</u>

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

<u>Other Participants</u>
Steve Bowman, UGS

SUMMARY
EIGHTH MEETING
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
Wednesday & Thursday, August 8 & 9, 2012
Utah Department of Natural Resources Building
1594 West North Temple, Salt Lake City, Utah

WELCOME AND INTRODUCTION

Working Group on Utah Earthquake Probabilities (WGUEP) Chair Ivan Wong called Meeting Eight of the WGUEP to order at 10:30 a.m. After welcoming the Working Group members and UGS staff (attachment 1), Ivan reviewed the meeting agenda (attachment 2), recapped WGUEP progress to date, and reviewed the current WGUEP task list. Ivan stated that the principal goals of this meeting were to (1) decide on the final central Wasatch fault zone (WFZ) paleoseismic parameters, (2) decide on the appropriate paleoearthquake magnitude regressions and their respective weights for calculating M_{max} for WGUEP category A, B, and C faults, (3) review the WFZ and Great Salt Lake-Oquirrh fault zone (GSL-OFZ) logic trees, and (4) review preliminary results of the WGUEP earthquake probability calculations.

TECHNICAL PRESENTATIONS

The meeting then moved to a series of technical presentations and issue updates. Available PowerPoint presentations for the technical presentations are at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2012B_Presentations.pdf. Note that not all technical presentation PowerPoints are included, the WGUEP considers the final central WFZ paleoseismic parameters, details of the WFZ and GSL-OFZ logic tree, and the results of the earthquake probability calculations proprietary to this process and are not part of public records under the Utah Government Records Access and Management Act until released in the final WGUEP report. Additionally, some technical presentations did not include a PowerPoint presentation.

Wednesday, August 8

- Final Data for Central WFZ – Chris DuRoss
- Poisson & BPT Parameter Estimates – Nico Luco
- Geodetic Modeling – Mark Petersen and Jim Pechmann (no PowerPoint)
- Update on Consensus Wasatch Front Earthquake Catalog – Walter Arabasz and Jim Pechmann
- Logic Trees for Wasatch and Great Salt Lake-Oquirrh Fault Zones – Patricia Thomas

Thursday, August 9

- Preliminary Results (Earthquake Probability Calculations) – Patricia Thomas

ISSUE DISCUSSIONS

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

Final Data for Central Wasatch Fault Zone

Chris DuRoss presented a Paleoseismology Subgroup update on the final paleoseismic data for the central segments of the WFZ. These data are not presented here because the WGUEP considers them proprietary to this process until released in the final WGUEP report. In the final report, details of the paleoseismic parameters will be presented in 11 appendices:

- Appendix A - Central WFZ OxCal summary
- Appendix B2 - OxCal output data
- Appendix C - Earthquake timing – central WFZ rupture models
- Appendix D - Single segment earthquake recurrence
- Appendix E1 - Displacement per site
- Appendix E2 - Displacement per rupture
- Appendix E3 - Displacement per source
- Appendix E4 - Displacement per source summary
- Appendix E5 - Displacement along strike
- Appendix F1 - Slip rates for central WFZ
- Appendix F2 - Summary of slip rates and weighted mean rate

Chris noted that since the WGUEP meeting in February 2012, (http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2012A_Summary.pdf and http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2012A_Presentations.pdf) only minor changes have been made by the Paleoseismology Subgroup to the consensus WFZ paleoseismic parameters. The changes were chiefly to minimum and mean displacement values for the Provo segment. A draft of the fault parameters report is complete and has been distributed within the WGUEP for review. In his PowerPoint, Chris showed tables and figures from the draft report that summarize: (1) earthquake timing for the central WFZ, (2) correlation of surface-faulting earthquakes for the Salt Lake City segment, (3) mean recurrence intervals for the central WFZ, (4) displacement per source on the central WFZ, (5) vertical slip rates for the central WFZ, (6) possible multisegment ruptures for the central WFZ, and (6) rupture models and weights for the central WFZ.

Poisson and Brownian Passage Time Parameter Estimates

Nico Luco discussed the Poisson "rate" parameter λ (lambda), and the Brownian Passage Time (BPT) "repeat time" parameter μ (mu). For each parameter, he discussed the approach used for determining those parameters in the Central and Eastern United States Seismic Source Characterization report (http://www.ceus-ssc.com/PDF/012712EPRI1021097.zip), provided examples using WFZ data, and summarized his WFZ results. Those data are summarized in Nico's PowerPoint presentation at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2012B_Presentations.pdf.

Nico noted that λ is an uncertainty function into which he will eventually also incorporate uncertainty in T (time), but that for the WFZ, the uncertainty due to T is swamped by the uncertainty introduced by the small earthquake dataset (x events in y years). Nico noted that with fewer events, the earthquake distribution gets wider (less specific). As an example, he presented a multisegment example with return period ends of 23,733 and 1198 years. Mark Petersen asked if these kinds of numbers are reasonable, since we are essentially talking about an event that we aren't sure has happened even once in 6000 years.

A discussion ensued regarding the weighting assigned to the various rupture scenarios for the WFZ—is 0.5 for single segment ruptures too low? Mark indicated that he thought 0.5 is too high for the single segment rupture model. However, it was the general consensus of the working group that the most probable rupture scenario for the WFZ is one consisting of all single segment ruptures and that a weight of 0.5 is about right or even a low value.

With regard to the BPT model, μ = arrival times and α = aperiodicity, which are used to inform a time dependent likelihood function. The current WFZ logic tree only incorporates time dependence for the single segment rupture scenario model. Ivan recommended incorporating time dependence for segments with only single segment ruptures in the rupture scenario models that include some multisegment ruptures (i.e., a mix of time dependent single segment ruptures and time independent multisegment ruptures). In this approach, the current minimum rupture scenario model would be entirely time independent because in that model all of the central WFZ segments are involved in at least one multisegment rupture.

Ivan recommended a weighting for the single segment rupture scenario model of 0.7 for time dependent and 0.3 for time independent. Mark asked how we would moment balance such a model—stating that the process would likely be complicated and time consuming. The path forward for performing such a task is also unclear.

Geodetic Modeling

Jim Pechmann noted that he had agreed to apply Kostrov's equation to compare moment rate from the WGUEP probability model to the geodetic moment rate. Mark was to provide geodetic strain rates and Patricia was to provide moment rates from the probability model. Jim stated that he had only recently received this information and has not had time to make the necessary calculations for his comparison. Mark stated that he is computing maximum shear and dilatation rates. So far, the geodetic rate without a background factor is about two times greater than the fault rate, which is about what was seen in earlier studies. A question was raised about what to do with the shear moment? Are there strike-slip faults in the WGUEP study area to which the shear can be assigned? Bob Smith stated that the shear likely comes from the big bend on the southern WFZ.

Jim stated that it is his intention to make his comparison and to discuss the results/difference between geodetic and geologic slip in the final WGUEP report. At present, it appears that the difference amounts to roughly one **M** 5.8 earthquake per year.

Update on Consensus Wasatch Front Earthquake Catalog

Walter Arabasz summarized the tasks required to create a consensus Wasatch Front earthquake catalog, with the ultimate goal of unifying the University of Utah Seismograph Stations (UUSS) catalog with the U.S. Geological Survey (USGS) National Seismic Hazard Maps catalog for the entire Utah region.

Summary of Tasks

- Compile and evaluate available info on earthquake size in the WGUEP/Utah region, both for pre-instrumental and instrumental data.

- Assess magnitude uncertainties and rounding errors.

- Derive relationships between M_w and other size measures, carefully using orthogonal regression, when appropriate, to avoid propagation of systematic errors into frequency-magnitude relations.

- Calculate uniform magnitudes and tabulate uncertainties needed for rate corrections.

- Compile catalog for the WGUEP study region (and surrounding buffer region for declustering), including merging of UUSS and key USGS catalogs.

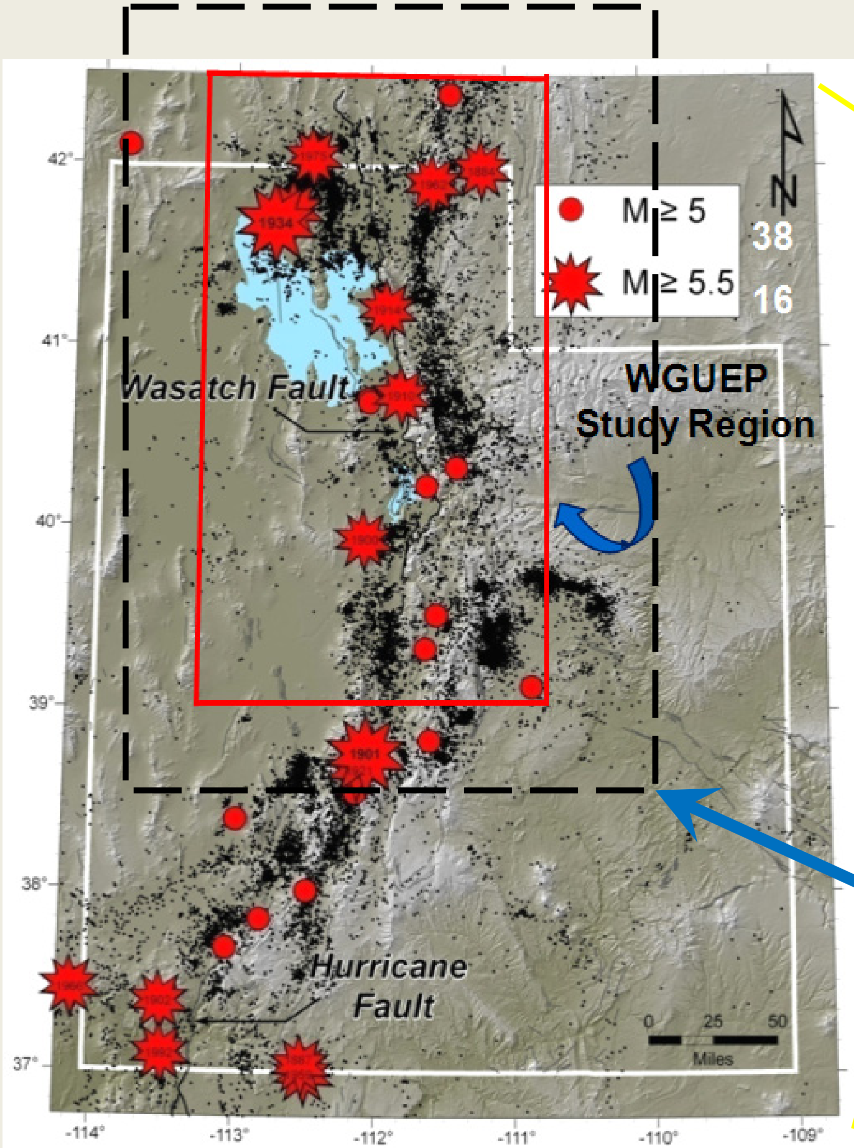
- Remove duplicates and non-tectonic events.

- Substitute hypocenters from special studies.

- Assess catalog completeness.

- Pass catalog to URS and USGS analysts for declustering and processing.

See Walter's PowerPoint presentation at http://geology.utah.gov/ghp/workgroups/pdf/wguep/WGUEP-2012B_Presentations.pdf for details pertaining to each task and current project status. The figure below shows the region of interest for which the catalog is being compiled.



Area for which a WGUEP consensus earthquake catalog is being generated.

"Utah Region"

Desired goal: Unify UUSS and NSHM catalogs for the entire Utah region

Immediate goal: WGUEP + 0.5º buffer zone for declustering

Walter's conclusions regarding the consensus catalog to date include:

- Complexity of project far greater than bargained for
- Methodology well in hand
- Important part of the end game is a unified UUSS/NSHM catalog for the Utah region
- Working on expedited processing for WGUEP purposes

Logic Trees for Wasatch and Great Salt Lake-Oquirrh Fault Zones

Patricia Thomas gave a PowerPoint presentation showing the current status of the logic trees for the WFZ and GSL-OFZ. These data are proprietary to the WGUEP process, and therefore the PowerPoint is not available on the UGS website. The Working Group reviewed the details of the logic trees, paying particular attention to the weights assigned to the various logic tree branches. Many of these values remain under active discussion, as do other logic tree details (e.g., the appropriate M_{char} relations to use for calculating M_{max} for category A, B, and C faults), and may change in the future.

Preliminary Results Earthquake Probability Calculations

Patricia gave a PowerPoint presentation showing the preliminary results of the WGUEP earthquake probability calculations to date. These data are proprietary to the WGUEP process, and therefore the PowerPoint is not available on the UGS website. Topics covered in Patricia's presentation included:

- Wasatch Fault Zone Central Segments
  - Mchar Distributions (including multisegment ruptures)
  - Rupture Rates: Recurrence Intervals (RI) vs. Slip Rates
  - Segment Moment Rates
  - Poisson Probabilities
  - BPT Probabilities
- Wasatch Fault Zone End Segments
- Wasatch Fault Zone Unsegmented
- Great Salt Lake Fault-Oquirrh Fault Zone
- Other Faults
- Remaining Inputs
  - Final RI distributions for all rupture sources and models
  - Multisegment rupture rates based on segment slip rates (moment balanced rates)
  - Weighting on slip rate versus recurrence interval-based rates for all five segmented models of central Wasatch fault zone
  - Background seismicity

Antithetic fault inputs

Latitude and longitude of fault endpoints and segment boundaries

Discussion ensued regarding the correct b value to use for faults in the Wasatch Front Region—currently using b = 0, but not sure if that is an appropriate value. It was also suggested that the name of the "truncated exponential model" be changed to something less confusing; however, a satisfactory replacement name was not agreed upon.

Mark Petersen called the WGUEP's attention to a recent report on magnitude scaling relations prepared by GNS Science for the Faulted Earth and Regionalisation Global Component of the Global Earthquake Model (Stirling and Goded, 2012). The report evaluated 72 magnitude-area and magnitude-length scaling relations, and recommended which of the 72 (18 total) are suitable for application to the Global Earthquake Model. The Stirling and others (2002) relation was one of the scaling relations evaluated, and the report states that "The authors [of the relation] did not intend this regression to be used in seismic hazard studies, so it should only be used if a large number of regressions are required for a logic tree framework." This information resulted in considerable discussion within the WGUEP, because the Stirling and others (2002) relation is one of the magnitude scaling relations being considered by the WGUEP for calculating M_{max} within the Wasatch Front Region. Jim Pechmann indicated that he was not happy with the Stirling and others (2002) relation because it censures low displacement earthquakes and focuses only on larger displacement events. The Paleoseismology Subgroup was tasked to follow up on this issue.

David Schwartz commented that the numbers used for the Bear River fault zone in the probability calculations are incorrect. He does not know what the correct numbers should be, but based on recent investigations by the USGS on the fault, he feels that the numbers will eventually have to be revised. Likewise, Susan Olig stated that the recurrence intervals used in the probability calculations for the GSL-OFZ are too short and violate the paleoseismic data for that fault.

Major issues that surfaced after review of the preliminary probability calculations include:

- Magnitude scaling relations need further evaluation.

- Does the current WGUEP model include enough time dependence? Ivan proposed revising the model to include 0.8 time dependence and 0.2 time independence.

- Approach to computing rates for multisegment ruptures needs further clarification, specifically the weighting of rates based on grouped ruptures and individual rupture rates, the grouping scheme, and the incorporation of judgment to limit the statistical uncertainty. Use group and individual rates and maybe coefficient of variation?

- Should the rupture scenario weights be revised? A possible, new weighting scheme was proposed as follows:
  Segmented = 0.7
  Multisegment A = 0.05, B = 0.05, C = 0.075, Min = 0.025 (0.2 total)
  Unsegmented = 0.1

MEETING ADJOURNED

WGUEP Meeting Eight was adjourned at 12:00 p.m. A date for Meeting Nine will be established once the results of the URS/UGS National Earthquake Hazard Reduction Program proposal requesting an additional year of funding for the WGUEP process become known – likely in October.

REFERENCES

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.

Stirling, M.W., and Goded, T., 2012, Magnitude and scaling relationships—Report produced for the GEM faulted earth and regionalisation global components: GNS Science, Miscellaneous Series 42, ver. 2, 35 p.

ATTACHMENT 1

Attendance

Working Group on Utah Earthquake Probabilities
Meeting #8

Walter Arabasz, UUSS
Tony Crone, USGS
Chris DuRoss, UGS
Mike Hylland, UGS
Nico Luco, USGS
Bill Lund, UGS, Coordinator
Susan Olig, URS Corporation
James Pechmann, UUSS
Steve Personius, USGS
Mark Petersen, USGS
Dave Schwartz, USGS
Bob Smith, UUGG
Patricia Thomas, URS Corporation
Ivan Wong, URS Corporation, Chair

Others presenting or assisting the Working Group
Steve Bowman, UGS Liaison to WGUEP

ATTACHMENT 2
AGENDA
WORKING GROUP ON UTAH EARTHQUAKE PROBABILITIES
MEETING #8
Wednesday/Thursday, 8 & 9 August 2012
Utah Department of Natural Resources Building
1594 West North Temple, Salt Lake City

<u>Wednesday, 8 August (Room 1040-1050)</u>

10:30 – 10:45	Overview of Agenda and Review of Last Meeting's To Do List	Ivan
10:45 – 11:30	Final Paleoseismic Parameters for the Central WFZ	Chris
11:30 – 12:15	Poisson and BPT Parameter Estimates for the WFZ	Nico
12:15 – 1:00	Lunch	
1:00 – 1:30	Geodetic Modeling	Jim and Mark
1:00 – 2:00	Update on Consensus Wasatch Front Earthquake Catalog	Walter
2:00 – 3:00	Review Wasatch Fault Logic Tree	Patricia
3:00 – 3:15	Break	
3:15 – 5:00	Review Wasatch Fault Logic Tree	Patricia

<u>Thursday, 8 August (Room 2000)</u>

8:00 – 8:30	Continental Breakfast	
8:30 – 10:00	Preliminary Earthquake Probability Results	Patricia
10:00 – 10:15	Break	
10:15 – 12:00	Preliminary Earthquake Probability Results (continued)	Patricia
12:00	Adjourn	

<u>WGUEP Members</u>

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

<u>Other Participants</u>

Steve Bowman, UGS

APPENDIX 4 – WSSPC NATIONAL AWARDS IN EXCELLENCE FOR RESEARCH NOMINATION

NATIONAL EARTHQUAKE CONFERENCE

Award Category (check all that apply)

- ☐ **Mitigation**
- ☐ Response & Recovery
- ☐ Plans/Materials
- ☐ Use of New Technology
- ☐ **Innovations (i.e. Private/Public Partnership)**
- ☐ **Research**
- ☐ Non-Profit Agency Efforts
- ☐ Multi-Jurisdictional Planning
- ☐ **Outreach**

Nominated Program, Project, or Product

Nominated Program, Project or Product: Utah Earthquake Working Groups

Nominated Administering Organization: Utah Geological Survey

Contact Name/Title: Dr. Richard Allis, Director

Street: P.O. Box 146100

City: Salt Lake City State: Utah Zip: 84114-6100

Telephone: 801.537-3300 Fax: 801-537-3400

Email: rickallis@utah.gov

Nomination Made By *(must be nominated by someone outside the nominated organization)*

Name: Roger Evans, Park City Municipal Corporation

Organization Affiliation: Utah Seismic Safety Council

Street: 445 Marsac Ave. (P.O. Box 1480)

City: Park City State: UT Zip: 84060-1480

Telephone: (435) 615-5113 Fax: 435-615-4905

Email: revans@parkcity.org

1. **2012 NATIONAL AWARDS IN EXCELLENCE NOMINATION FORM**
UTAH EARTHQUAKE WORKING GROUPS

The Utah Geological Survey (UGS), in cooperation with the Utah Seismic Safety Commission (USSC), and the U.S. Geological Survey (USGS) convenes annual Utah Earthquake Working Group meetings each February in Salt Lake City, Utah. The Utah Quaternary Fault Parameters Working Group, Liquefaction Advisory Group, and Ground Shaking Working Group each meet to review research activities, re-evaluate long-term plans for producing maps, and develop partnerships for investigations and topics for future National Earthquake Hazard Reduction Program (NEHRP) proposals. The results of the three working group meetings are reported in annual meeting summaries posted on the UGS web site (http://geology.utah.gov/ghp/workgroups/index.htm).

Each working group has achieved consensus regarding the types of earthquake-hazard maps needed, new data required, and preferred data collection and mapping techniques. The working groups have developed partnerships and identified projects for which to pursue funding. These results have been used by the USGS to develop Utah priorities for the annual USGS NEHRP external research support grant opportunity announcement. Because the meetings are held in February, just prior to the annual grant opportunity release, discussions and momentum gained at the meetings are translated into proposals by researchers to the USGS.

Working group members include geologists, engineers, seismologists, and geophysicists from the USGS, UGS, University of Utah, Utah State University, Brigham Young University, and consulting companies and state agencies. Additionally, representatives from the USSC, and other state agencies and professional organizations are invited to attend the meetings.

The main goal of the Utah Quaternary Fault Parameters Working Group is to characterize active fault sources in Utah. The working group began by developing consensus slip-rate and recurrence interval data for all Utah trenched faults in 2005. The working group also developed an initial priority list of faults requiring additional study and, based on each year's paleoseismic investigations, has updated the list annually. As new paleoseismic data became available, the working group modifies its consensus slip-rate and recurrence-interval values as necessary. Other working group issues include the Wasatch Front time dependent earthquake probability model, refining the surface trace of the Salt Lake City segment of the Wasatch fault on the National Seismic Hazard Maps (NSHM), the relation of the West Valley fault zone to the Wasatch fault., and making periodic recommendations to the USGS regarding which Utah faults should be included in future USGS NSHM updates.

The Liquefaction Advisory Group's goal is to produce maps showing annual probabilities of liquefaction and liquefaction-induced ground displacement, and extending their pilot-project investigations in Salt Lake Valley to Utah and Davis Counties, particularly regarding compilation of a comprehensive regional geotechnical database. The working group has dealt with issues related to under-sampling of geologic units, uncertainty analysis, compilation of newly available geotechnical data, and conducting additional cone penetrometer investigations in downtown Salt Lake City. Work is underway to complete current projects and publish liquefaction maps for use by local government planners and other users.

The Ground Shaking Working Group is developing a Community Velocity Model (CVM) in order to develop large-scale spectral acceleration maps for the Wasatch Front that incorporate site and basin-shape effects. A team from San Diego State University recently updated the prior model with newly available data that included both shallow-shear-wave velocity and deep-basin-structure effects on ground motion. The UGS has distributed the updated CVM on its web site. Current efforts involve validating the CVM, expanding the CVM to include Tooele and Rush Valleys and the Wasatch back valleys, updating the CVM with intermediate-depth data, and continuing to work toward producing Wasatch Front Urban Seismic Hazard Maps.

2. How long has the program been operational? Since: Month February Year 2003
(Note: In order to be considered for a 2012 National Award in Excellence the program must have been operational since at least December 2010.)

3. What are the major purposes of the program? See attached program summary.

4. Describe the specific activities and operations of the program. See attached program summary.

5. Does it take a new and creative approach or method? If yes, please describe. Yes, to our knowledge this is the only program like it in the U.S. The Earthquake Working Groups have been highly successful at advancing earthquake-hazard research in Utah by bringing together researchers and professionals from varied organizations to advance earthquake-related knowledge. The UGS has been asked by the USGS to make presentations on this program to other states in the hope of generating similar programs elsewhere.

6. What were the start-up costs and source(s) of funding?

Budget: $98,492_ Source: U.S. Geological Survey and Utah Geological Survey

What are the annual operational costs and source(s) of funding?

Budget: $76,537 (2011)_ Source: U.S. Geological Survey and Utah Geological Survey

7. How many employees (full-time equivalent) work(ed) with the program? 0.5 (2011)

8. To the best of your knowledge, did the program originate with you? __X__ Yes _____ No

Are you aware of similar programs elsewhere? _____ Yes __X_ No

9. Has the program been fully implemented? _____ Yes __X_ No
If no, what actions remain to be taken? This is a long-term program that will continue to operate as long as relevant earthquake-hazard research remains to be identified, prioritized, and undertaken in Utah. The program is approaching a decade old and will continue into the foreseeable future.

10. Is there evidence that the program has been effective in achieving its stated purpose(s)?
Briefly summarize evaluations (pro and con) of how well it has addressed the defined problem(s) or issue(s). This program has spurred earthquake hazard research in Utah that includes multiple paleoseismic investigations of active faults in Utah (http://geology.utah.gov/ghp/consultants/paleoseismic series.htm), it spurred formation of the Working Group on Utah Earthquake Probabilities (http://geology.utah.gov/ghp/workgroups/wguep.htm), has resulted in the creation of a Community Velocity Model for the Wasatch Front (http://geology.utah.gov/ghp/consultants/geophysical_data/cvm.htm), and development of liquefaction-hazard maps for Salt Lake Valley (http://www.civil.utah.edu/~bartlett/ULAG/).

11. How has the program changed since its inception? What limitations or obstacles might others expect to encounter if they attempt to adopt it? Yes, an additional short-term (2 years) working group to prepare time-dependent earthquake probabilities for the Wasatch Front has been added to the program. This program requires the volunteered efforts of a broad spectrum of technical experts to

be successful. Generating their support can be difficult, but once they are on board, the success begins almost immediately.

12. Additional comments:
Utah Earthquake Working Groups List of Contributors (2003 – 2011)

Principal Investigator
Steve Bowman, Utah Geological Survey (2008 – 2011)
Gary Christenson, Utah Geological Survey (2003 – 2007)

Utah Quaternary Fault Parameters Working Group
William Lund, Utah Geological Survey, Facilitator and Liaison
Larry Anderson, U.S. Bureau of Reclamation
Bill Black, Western GeoLogic
Ronald Bruhn, University of Utah
Wu-Lung Chang, University of Utah
Gary Christenson, Utah Geological Survey
Tony Crone, U.S. Geological Survey
David Dinter, University of Utah
Chris DuRoss, Utah Geological Survey
Jim Evans, Utah State University
Kathleen Haller, U.S. Geological Survey
Ronald Harris, Brigham Young University
Daniel Horns, Utah Valley State College
Michael Hylland, Utah Geological Survey
James McCalpin, GEO-HAZ Consulting
Alan Nelson, U.S. Geological Survey
Susan Olig, URS Corporation
James Pechmann, University of Utah Seismograph Stations
Steve Personius, U.S. Geological Survey
Mark Petersen, U.S. Geological Survey
Lucy Piety, U.S. Bureau of Reclamation
Christine Puskas, University of Utah
Jamie Robinson, Professional Service Industries
Robert Smith, University of Utah
Ivan Wong, URS Corporation

Ground Shaking Working Group
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Greg McDonald, Utah Geological Survey Liaison (2008 – 2011)
Walter Arabasz, University of Utah Seismograph Stations
Francis Ashland, Utah Geological Survey
Steve Bartlett, University of Utah
Jim Bay, Utah State University
Relu Berlacu, University of Utah Seismograph Stations
Wulung Chang, University of Utah Seismograph Stations
Travis Gerber, Brigham Young University
Marv Halling, Utah State University

Keith Koper, University of Utah Seismograph Stations
Harold Magistrale, San Diego State University
Morgan Moschetti, U.S. Geological Survey
Kim Olsen, San Diego State University
Mike Olson, San Diego State University
Kris Pankow, University of Utah Seismograph Stations
Jim Pechmann, University of Utah Seismograph Stations
Mark Petersen, U.S. Geological Survey
Kyle Rollins, Brigham Young University
Daniel Roton, San Diego State University
Gerard Schuster, University of Utah
Bob Smith, University of Utah
Bill Stephenson, U.S. Geological Survey
Ken Stokoe, University of Texas

Liquefaction Advisory Group

Steve Bartlett, University of Utah, Facilitator
Michael Hylland, Utah Geological Survey, Liaison
Loren Anderson, Utah State University
Jim Bay, Utah State University
Anthony Crone, U.S. Geological Survey
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Dave Simon, Simon-Bymaster, Inc.
Barry Solomon, Utah Geological Survey
Aurelian Trandafir, University of Utah
Bill Turner, Kleinfelder, Inc.
Les Youd, Brigham Young University

Deadline: All nominations and supporting materials must be completed and received by WSSPC by **Friday, December 30, 2011**, to be considered for the *2012 National Awards in Excellence*.

Email completed application and supporting materials to Amy Lewis: alewis@wsspc.org.

WESTERN STATES SEISMIC POLICY COUNCIL

2012 National Awards in Excellence
Western States Seismic Policy Council
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