# UTAH EARTHQUAKE WORKING GROUPS, DATABASES, AND RESEARCH PROJECTS, 2003-2006

## FINAL TECHNICAL REPORT FOR UGS-USGS COOPERATIVE AGREEMENT 03HQAG0008

By

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## ABSTRACT

The Utah Geological Survey (UGS) and U.S. Geological Survey (USGS) entered into a cooperative agreement in 2003 to establish working groups to coordinate earthquake research in Utah, develop and implement long-term plans to produce the next generation of earthquake-hazard maps, and characterize faults believed to be sources of large earthquakes. Four working groups (Ground Shaking, Liquefaction, Quaternary Fault Parameters, and Earthquake-Induced Landslides) met during the period from 2003 to 2006 to develop partnerships and priorities for future investigations.

To support development of earthquake-hazards maps, the UGS compiled three databases to accurately reflect the status of existing data on 1) shallow-shear-wave velocities (Vs30), 2) deep-basin structure, and 3) geotechnical landslide shear strengths. The shallow-shear-wave-velocity database is statewide and includes all shear-wave-velocity data to depths of 30 m or more using downhole, cone penetrometer, and geophysical methods. The deep-basin-structure database covers the Wasatch Front from Weber to Utah Counties, and includes selected deep water wells; oil and gas/geothermal exploration boreholes, particularly those that encountered bedrock; and deep geophysical data, mostly oil-company seismic-reflection lines in and around Great Salt Lake. The geotechnical landslide shear-strength database is statewide and includes laboratory soil-test data from various sources, principally geotechnical consultants and the Utah Department of Transportation.

During the first three years of the cooperative agreement, the UGS also performed a variety of scientific studies to map and characterize faults, identify and assess possible earthquake-induced landslides, and evaluate earthquake recurrence data and fault behavior. The UGS also assisted other USGS-funded earthquake researchers working in Utah and published final reports of completed research.


## INTRODUCTION

The UGS and USGS entered into an agreement in 2003 for cooperative earthquake-hazards studies in Utah. One goal of the cooperative studies ultimately is to produce the next generation of earthquake-hazards maps, including 1) large-scale urban seismic-hazard maps incorporating the latest fault source parameters and shallow shear-wave-velocity (Vs30), deep-basin-structure, and other effects; and 2) new liquefaction and earthquake-induced landslide maps depicting ground displacements or other parameters as appropriate. To initiate the process, the UGS established four technical working groups (Ground Shaking, Liquefaction, Quaternary Fault Parameters, and Earthquake-Induced Landslides) and held meetings during the period from 2003 to 2006 to coordinate studies and develop plans for producing hazard maps. All working groups remained active at the end of the period except for the Earthquake-Induced Landslide Working Group, which became inactive in 2004.

To aid in assessing data needs, the UGS compiled databases of existing shear-wave-velocity, deep-basin-structure, and geotechnical landslide shear-strength data on a compact disk (CD). Information needed to use and understand each database is included below and in the introductory material on the CD. Additional funding was provided during the first three years of the cooperative agreement for the UGS to perform scientific studies. These studies concentrated on seismic source characterization of the Wasatch fault, principally the end segments, but included other fault and landslide studies. The UGS also provided assistance to the USGS and other NEHRP researchers, including manuscript review and publication.

## EARTHQUAKE WORKING GROUPS

Meetings of the Earthquake Working Groups are held each year, and results of meetings are reported in each of the annual UGS Final Technical Reports to the USGS from 2003 to 2006 (Christenson and others, 2004, 2005, 2006; Christenson, 2007). Each working group has developed a consensus among the technical experts regarding the types of earthquake-hazard maps needed, new data required, and preferred data-collection and mapping techniques. Working groups developed partnerships and identified projects to pursue funding. Results of this program help define research objectives, data requirements, and hazards mapping needs. These results have also been used by the USGS to help develop the next year's priorities in Utah for the USGS National Earthquake Hazards Reduction Program (NEHRP) Request for Proposals (RFP) for Intermountain West studies. Meetings were held in February/March, coincident with the release of the USGS NEHRP RFP, so discussions and momentum gained at the meetings could translate into proposals to the USGS.

Working group members (appendix A) include geologists, engineers, seismologists, and geophysicists from Utah State University, Brigham Young University, University of Utah, UGS, USGS, and various consulting companies and state agencies. Personnel representing the American Society of Civil Engineers, Association of Engineering Geologists, Utah Seismic Safety Commission, Salt Lake County, and other state agencies were invited to observe the proceedings and participate as desired (Invited Observers, appendix A). Final working group plans outline research needs for future earthquake-hazards mapping and are shown in appendices B, C, and D.

The Ground Shaking Working Group (appendix B) concentrated on developing a community velocity model (CVM) for use in producing large-scale urban seismic-hazard (spectral-acceleration) maps for the Wasatch Front that incorporate both shallow-shear-wave velocity (Vs30) and deep-basin-structure effects on ground motions. Early steps in the process involved collecting additional shallow-shear-wave-velocity (Vs30) data to characterize shallow (upper 30 m) site conditions. In addition, intermediate to deep (100-300 m) shear-wave-velocity profiles and deep P-wave-velocity profiles to bedrock were obtained using a variety of geophysical techniques to better characterize velocity gradients and basin shape. These data are in the process of being incorporated into a CVM which will then be used by the USGS, UGS, and other partners to develop large-

scale spectral-acceleration maps for the Wasatch Front that incorporate site and basin-shape effects, if data are adequate.

The Liquefaction Working Group (appendix C) set a long-term goal to produce maps showing annual probabilities of liquefaction and liquefaction-induced ground displacement and, if possible, settlement for the Wasatch Front. The working group began with a pilot project in northern Salt Lake Valley to compile geotechnical data, characterize geologic units, and develop computer code to produce the liquefaction potential and ground displacement maps. The framework for a comprehensive Wasatch Front geotechnical database was developed, which now includes all of Salt Lake Valley. Compilation has begun in Utah Valley. Probabilistic liquefaction-induced ground displacement (lateral spreading) maps have been developed for Salt Lake County, and steps are underway to put them into a format for use by local-government planners. Work in Utah Valley was initiated in the final year of the project, and the ultimate plan is to expand mapping to include Weber and Davis Counties.

The main goal of the Quaternary Fault Parameters Working Group is to characterize fault sources. It began by developing a consensus among paleoseismologists working in Utah regarding earthquake timing, slip rates, and recurrence intervals for all trenched Utah faults (Lund, 2005). The working group developed a list of priorities for future paleoseismic fault studies, and coordinates and evaluates fault studies as they are completed. In addition, the working group and UGS made recommendations regarding which faults should be included in the 2007 update of the USGS National Seismic Hazard Maps (NSHMs).

The Earthquake-Induced Landslide Working Group (appendix D) met in 2003 and 2004 and recognized a lack of data and lack of support for detailed studies as significant problems. The working group initially identified several pilot projects to investigate methods for producing maps given the lack of data. Later, however, the working group was not successful in reaching a consensus on future earthquake-induced landslide studies along the Wasatch Front. Support for preparing earthquake-induced landslide hazards maps is generally lacking, and no clear regulatory framework or interest among local governments for using such maps seems to exist. As a result, the Earthquake-Induced Landslide Working Group became inactive in 2005. Their plan from 2003 is shown in appendix D, but future work is not being pursued.

In addition to the annual working group meetings, we held an earthquake conference on February 26, 2004. The conference preceded the working group meetings in part to inform working group members of first-year plans, but mainly the conference was open to all local earth scientists and engineers to serve as a forum to inform them of working group activities and research results. Total conference attendance was about 150.

## DATABASES

Working groups originally planned to produce 1) large-scale urban seismic-hazard (ground-shaking) maps, based on a CVM incorporating shallow shear-wave-velocity (Vs30), deep-basin-structure, and other effects; and 2) new liquefaction and earthquake-induced landslide maps. To aid in assessing data needs, the UGS compiled databases to identify existing data on 1) shallow-shear-wave velocities (Vs30), 2) deep-basin structure, and 3) geotechnical landslide shear strengths. Details of each database are included in Christenson and others (2004).

The databases are in an interactive GIS-format (HTML Image Mapper®, version 3.0) that includes "point and click" maps, summary tables, and downloadable scans of original data and logs compiled onto a CD. A description of the data contained, criteria used in compiling data, and comprehensiveness of each database is given below. Sources of data are included in database entries. The CD is unpublished, but copies are available from the UGS upon request.

### Shallow-Shear-Wave Velocities

The shallow- (upper 30 m) shear-wave-velocity (Vs30) database was originally compiled for the UGS site-response map of Salt Lake Valley and updated for the later revised shear-wave-velocity/site-class map. The database now covers the entire Wasatch Front and is statewide, although few data exist outside the Wasatch Front.

The database includes only shear-wave-velocity measurements to depths of 30 m or greater measured directly using downhole, cone penetrometer (CPT), and spectral-analysis-of-surface-waves (SASW) and Rayleigh-wave-inversion geophysical methods. No data shallower than 30 m, and no standard-penetration test or undrained shear-strength conversions are included. A database summary table is available that includes Vs30 (mean Vs for the upper 30 m) values calculated using equation 16-44 in the 2003 International Building Code (International Code Council, 2003).

Most of the shear-wave-velocity data in the database were collected for private developments and public projects, including Utah Department of Transportation (UDOT) data, and were obtained from local geotechnical consultants and government agencies. We also contacted local contractors that perform downhole and CPT Vs testing. Work throughout the Wasatch Front in 2004 and 2005 by Utah State University in cooperation with the UGS and the University of Utah Seismograph Stations under USGS NEHRP grants using SASW-methods are included in the database.

The summary table of the database is downloadable as an MS Excel® spreadsheet that contains general location and source information as well as Vs30, engineering-geologic-unit, and IBC site-class information. In many cases, location coordinates are not precise and may represent a general site locality rather than individual test locations. Shear-wave-velocity data for individual tests are available as downloadable scans (PDF

format) of graphic and/or tabulated logs and supplemental information, including lithologic logs and geotechnical lab data where available.

## Deep-Basin Structure

The deep-basin-structure database includes selected logs of deep water wells and oil and gas/geothermal-exploration boreholes, and deep seismic reflection and refraction sections. We included only logs of boreholes and wells that encountered bedrock or are near wells that encountered bedrock in Wasatch Front valleys from Weber to Utah Counties. Deep geophysical data consist mostly of publicly available oil-exploration seismic sections and are limited to Salt Lake Valley, Great Salt Lake, and the eastern shore area of Great Salt Lake.

The deep-basin data are summarized in two MS Excel® spreadsheets (Deep Well and Seismic) that contain general location, source, and depth information. Individual logs are available as PDF-format scans of delimited text files or graphic logs. The data were plotted from coordinates or figures in referenced reports, and in many cases locations are not precise and limited by original map scales. Most of the water-well locations were supplied by the Utah Division of Water Rights (UDWR) as a GIS shape file. The locations are not precise and have not been verified. In many cases, location coordinates may represent a general site locality rather than individual test locations.

Seismic reflection/refraction data from published references are few and limited to surveys performed in Salt Lake Valley and Great Salt Lake. The data consist of several deep seismic-reflection lines in Great Salt Lake and the east shore area, two good-quality seismic-reflection lines in northern Salt Lake Valley, two unreversed seismic-refraction profiles in western and southern Salt Lake Valley, and a short seismic-refraction survey near the mouth of Little Cottonwood Canyon. Seismic data are downloadable as PDF-format scans of seismic sections found in the referenced material.

## Geotechnical Landslide Shear Strengths

The geotechnical landslide shear-strength database includes laboratory soil-test data performed for landslide studies. The database is statewide although most data are concentrated along the Wasatch Front. Because shear-strength testing methods and parameters are highly variable, the test results are separated into many categories. In many cases, the types of detailed information regarding testing conditions and methods that are needed to properly use the data were not provided in the reports, so considerable judgment is required when using the data.

The data will ultimately be summarized in an MSAccess database providing for easy searching, sorting, and statistical analysis of the data. The database includes shear-strength-test type, test results, soil type using the Unified Soil Classification System (USCS), and geologic unit (if given; otherwise interpreted by UGS). The data were plotted from coordinates or location maps from the original reports and may represent a general site locality rather than individual sample locations.

Sources of data are principally geotechnical consultant and UDOT reports. Specific sources are identified according to their HAZBIB number in the UGS Hazards Bibliography (Harty and others, 1992; updated edition available in UGS library). Most data were collected in the late 1980s as UGS personnel contacted local geotechnical consultants and copied test results when compiling HAZBIB. Subsequent data (1990s through present) are less comprehensive and are compiled from consultant's reports done for public agencies (local governments, UDOT) or submitted to public agencies and reviewed by the UGS.

## RESEARCH PROJECTS

During the first three years (2003-2005) of the contract period, the cooperative agreement helped fund a variety of research projects by the UGS to address earthquake hazards in Utah. Studies characterized the remaining unstudied end segments of the Wasatch fault in Utah, and looked at fault behavior of the central segments. Results of these and other studies are included in the four annual UGS Final Technical Reports to the USGS as listed below:

- Interim surficial geologic map of the Levan segment of the Wasatch fault zone, Juab and Sanpete Counties, Utah, by M.D. Hylland and M.N. Machette (Christenson and others, 2004)
- Earthquake-induced landslide studies, Salt Lake County, by F.X. Ashland and G.N. McDonald (Christenson and others, 2004)
- Interim surficial geologic map of the Fayette segment of the Wasatch fault zone, Juab and Sanpete Counties, Utah, by M.D. Hylland and M.N. Machette (Christenson and others, 2005)
- Paleoseismic reconnaissance of the Sevier/Toroweap fault, Washington and Garfield Counties, Utah, by W.R. Lund (Christenson and others, 2005)
- Paleoseismic (non-trenching) investigation of the Collinston and Clarkston Mountain segments of the Wasatch fault zone, Box Elder County, Utah, by M.D. Hylland (Christenson and others, 2006)
- The potential for multi-segment rupture on the central segments of the Wasatch fault zone, Utah, by C.B. DuRoss (Christenson and others, 2006)
- Basin and Range Province Earthquake Working Group seismic-hazard recommendations to the USGS National Seismic Hazard Mapping Program, edited by W.R. Lund (Christenson and others, 2006; Lund, 2006)

These reports represent significant scientific studies completed with the additional funding provided during the first three years of the cooperative agreement, and included convening the Basin and Range Province Earthquake Working Group for a 3-day meeting. This funding was cut back after the third year, so additional UGS efforts in the fourth year were reduced to assisting the USGS and other NEHRP-funded researchers with their work in Utah, and publishing their results as listed in Christenson (2007).

## ACKNOWLEDGMENTS

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International Code Council, 2003, International Building Code: Falls Church, Virginia, 655 p.

Lund, W.R., 2005, Utah Quaternary Fault Parameters Working Group – Review of Utah paleoseismic-trenching data and determination of consensus recurrence-interval and slip-rate estimates: Utah Geological Survey Bulletin 134, compact disk.

--- compiler, 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.

## APPENDIX A

## 2006 UTAH EARTHQUAKE WORKING GROUP MEMBERS AND INVITED OBSERVERS

Ground Shaking Working Group
Ivan Wong, URS Corporation, Facilitator
Gary Christenson, UGS
Walter Arabasz, UUSS
Jim Pechmann, UUSS
Kris Pankow, UUSS
Bob Smith, UUGG
Gerard Schuster, UUGG
Kim Olsen, SDSU
Harold Magistrale, SDSU
Mark Petersen, USGS
Jim Bay, USUCEE
Marv Halling, USUCEE
Francis Ashland, UGS
Steve Bartlett, UUCE
Kyle Rollins, BYUCE
Ken Stokoe, UT
WuLung Chang, UUGG
Greg McDonald, UGS
Relu Berlacu, UUSS

Liquefaction Working Group
Steve Bartlett, UUCE, Facilitator
Barry Solomon, UGS
Bill Turner, Earthtec
Les Youd, BYUCE
Kyle Rollins, BYUCE
Loren Anderson, USUCEE
David Simon, SBI
Mark Petersen, USGS
Clifton Farnsworth, UDOT
Travis Gerber, BYUCE
Jim Bay, USUCEE
Grant Gummow, UDOT

Quaternary Fault Parameters Working Group
William R. Lund, UGS, Facilitator
Suzanne Hecker, USGS
Michael Hylland, UGS
Michael Machette, USGS

James McCalpin, GEO-HAZ Consulting
Alan Nelson, USGS
Susan Olig, URS Corporation
Dean Ostenaa, U.S. Bureau of Reclamation
Stephen Personius, USGS
David Schwartz, USGS
Mark Petersen, USGS
Kathleen Haller, USGS
James Pechmann, UUSS
Robert Smith, UUSS
Ivan Wong, URS Corporation
Chris DuRoss, UGS

Invited Observers (all Working Groups)
Bob Carey, UOES
Barry Welliver, USSC Chair
David Plehn, Chair, Utah Geotechnical Group, ASCE
Darlene Batatian, former Salt Lake County Geologist
Danny Horns, Chair, Utah Section, AEG
David Marble, Utah Dam Safety

Earthquake-Induced Landslide Working Group (inactive, did not meet in 2005 or 2006)
Francis Ashland, UGS, Facilitator
Randy Jibson, USGS
Tim McCrink, CGS
Robert Pack, USUCEE
Barry Solomon, UGS
Leslie Heppler, UDOT
Loren Anderson, USUCEE
Fulvio Tonon, UUGG
Jim Nordquist, AGEC
Jim Higbee, UDOT
Danny Horns, UVSC

## APPENDIX B

# UTAH PLAN FOR DEVELOPING THE NEXT GENERATION OF GROUND-SHAKING HAZARD MAPS

Developed by the Utah Ground-Shaking Working Group
**Adopted by the Utah Seismic Safety Commission and Utah Geological Survey**
Developed March-April, 2003; revised February, 2004

OBJECTIVE: The objective of this plan is to define future earth science research (exclusive of fault source characterization) that will provide vital information needed for developing earthquake ground-shaking microzonation hazard maps for the Wasatch Front, Utah. These maps will be useful for raising public and government awareness, emergency preparedness and response, urban planning, risk analyses, and as a comparison to building code-based and site-specific seismic design. Eventually, if acceptance is reached with the Utah UBC Commission and the engineering community, these maps could replace the Maximum Considered Earthquake Ground Motion maps and site coefficients contained in the IBC. Study-area priorities will be Salt Lake Valley and the Wasatch Front, including Tooele and Cache Valleys.

Research Needs

1. Develop a community velocity model for both site-response analysis (shallow site effects) and basin modeling of Wasatch Front basins to characterize Vs30 and Vs structure down to R1 (boundary between unconsolidated and semi-consolidated sediments) and R2 (boundary between semi-consolidated and consolidated sediments), principally using SASW/seismic-reflection surveys but any other velocity data as they become available. Timing: 2004-2006.

2. Evaluate seismic source and propagation path characteristics of Utah earthquakes (e.g., Q, kappa, stress drops, crustal effects, hanging-wall effects, directivity), and site amplification and geotechnical characteristics of Utah soils and rock (e.g., non-linear dynamic material properties) to improve ground-motion estimates. Timing: 2004-2007.

3. Perform 3D modeling using the community velocity model to evaluate the importance of basin structure (e.g., depth to R2, basin edge effects, steep basin boundary effects, focusing) on strong ground motions. Timing: 2005-2007.

4. Calculate the hazard and prepare large-scale probabilistic and scenario ground-shaking maps (scale of 1:50,000 to 1:100,000) incorporating site response, basin effects, and results of other investigations described above. These maps will undergo extensive peer review by the earthquake research community, the engineering community, and potential users, and will be published and distributed to individuals involved in earthquake hazard mitigation and the general public. Timing: 2007+.

## APPENDIX C

# UTAH PLAN FOR DEVELOPING THE NEXT GENERATION OF LIQUEFACTION HAZARD MAPS

Developed by the Utah Liquefaction Advisory Group
**Adopted by the Utah Seismic Safety Commission and Utah Geological Survey**
Developed March-April 2003; revised February 2004

(1) Create a liquefaction database of relevant geotechnical factors and develop Geographic Information System (GIS) methods for probabilistic liquefaction hazard assessment using the database, strong motion estimates from the USGS National Seismic Hazard Map Program and International Building Code 2003 site amplification coefficients to modify the strong motion estimates for soil effects. The proposed methods are being tested with a NEHRP grant for a pilot liquefaction-mapping project in north Salt Lake County during 2003 and 2004 (Federal FY 2004).

(2) Develop methods to perform uncertainty analyses and/or quantify the uncertainties associated with the liquefaction-hazard mapping.

(3) Correlate the GIS liquefaction database and surficial geological mapping to infer geotechnical and subsurface properties for similar geological units. These correlations will be used to better understand the liquefaction susceptibility of a given geological unit or facies and improve the quality of the liquefaction assessment for units that are either undersampled or have no subsurface sampling. Initial correlations will be developed during the pilot project and will continue in future projects (Federal FY 2005-2008) as data from additional geologic units and geographic areas are compiled.

(4) Compile the GIS database for other areas along the Wasatch Front using the pilot-project methods and complete liquefaction-hazard mapping for these areas. The preliminary priority of data compilation and mapping is: Salt Lake, Utah, Weber-Davis, and Cache Counties (Federal FY 2005-2008). Database compilation for south Salt Lake County may be proposed as a NEHRP project for Federal FY 2005.

(5) Develop probabilistic methods to map the amount of liquefaction-induced ground deformation (lateral-spread displacement and liquefaction-induced settlement). These methods will use existing correlations that relate thickness of liquefiable layers and other soil factors to the potential for lateral spread displacement and settlement. This mapping will be done for the same areas as the probabilistic liquefaction-hazard maps and will be completed during Federal FY 2005 to 2008. Liquefaction-induced ground deformation mapping in north Salt Lake Valley, the same area as the pilot project, may be proposed as a NEHRP project for Federal FY 2005.

(6) Study documented occurrences of deformed Quaternary soils to determine if deformation is liquefaction-induced or related to other mechanisms (for example, failure of underlying clay). Also, attempt to determine the age of failed soils to establish the liquefaction hazard posed by latest Pleistocene Lake Bonneville sands. Is the presence of these Pleistocene sands sufficient to indicate a high liquefaction hazard or, as suggested by criteria for liquefaction in California, does the Pleistocene age indicate a lower hazard? A limited study of documented occurrences may be proposed as a NEHRP project for Federal FY 2005.

## APPENDIX D

## UTAH PLAN FOR DEVELOPING THE NEXT GENERATION OF EARTHQUAKE-INDUCED LANDSLIDE-HAZARD MAPS

Utah Earthquake-Induced Landslide Working Group
July-September 2003 (not updated in 2004)

Future moderate and large earthquakes in Utah may cause damaging landslides including 1) the reactivation of pre-existing landslides and triggering of new deep-seated landslides in susceptible areas, 2) shallow landslides on moderate to steep slopes, and 3) rock falls from steep mountain slopes.

OBJECTIVE: Develop maps that illustrate the potential for earthquake-induced landsliding, including on slopes where otherwise a landslide hazard may not exist. These maps will be used for raising public awareness, emergency preparedness and response, urban planning, and risk analyses by land-use planners (special-study maps), emergency managers, and lifeline managers including the Utah Department of Transportation.

**Research Options**

1. Investigate and select an approach, possibly that of McCrink (2001), for generating earthquake-induced landslide-hazard maps as a pilot project. The pilot project would evaluate several options to map geologic units with similar shear strengths based on: 1) the existing shear-strength database, supplemented by a renewed search of data available from consulting firms and state agencies, 2) additional laboratory testing to obtain shear-strength data (if funding becomes available), and 3) the use of "best estimates" from an expert panel. Criteria for selecting a pilot project study area include the availability of 1:24,000-scale geologic mapping, shear-strength data, an adequate landslide inventory, and 10-meter digital elevation models (DEMs). Sensitivity analyses should evaluate the relative importance of these criteria in the final map outcome. The pilot project should address the relation between static and earthquake-induced landslide-hazard maps, and methods to produce dual-purpose maps. The feasibility of incorporating SINMAP (Stability Index Mapping) software into the project will be evaluated.

2. Create earthquake-induced rock-fall susceptibility maps using the methods of Harp and Noble (1993) in study areas along the Wasatch Front urban corridor (Ogden-Provo) and/or important transportation/lifeline corridors in mountain areas. Evaluate the practicality of the technique for covering large areas and define methods for determining runout distances and potential for larger rock avalanches.

3. Inventory existing landslides in an area of similar geology (such as the bluffs in the Weber River delta complex), collect data (such as slope, dominant grain size,

and ground-water conditions) that provides an understanding of stability/susceptibility to reactivation or local failure (including failure of slopes adjacent to landslides) during an earthquake, and assess the likely effects of earthquakes to improve our understanding of the actual hazard from earthquake-induced landslides.

4. Identify possible earthquake-induced landslides in the Wasatch Front and assess whether subsurface investigations could reveal ages of deposits or movement events allowing correlation with documented Wasatch Front surface-faulting earthquakes. Perform "paleoseismic" investigations of selected landslides and characterize site conditions that contribute to earthquake-induced landsliding.

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