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DEVELOPING AND IMPLEMENTING SHAKEMAP SCENARIOS USING HAZUS-MH

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ABSTRACT

The Federal Emergency Management Agency (FEMA) and the U.S. Geological Survey (USGS) have coordinated on the development of new products that support an extensive library of ShakeMap scenarios, largely based on the USGS National Hazard Map sources of earthquakes that are supporting Hazards U.S. (HAZUS) loss estimations. These scenarios are used to support a broad range of emergency management activities, including mitigation, recovery and preparedness planning, as well as exercises for response. To date these have been implemented as pilot studies under the National Earthquake Hazard Reduction Program (NEHRP) in Washington and Utah and more recently in Nevada. This paper describes the lessons learned during these pilots and the larger future initiative of the USGS Earthquake Hazards Program (EHP) in producing a comprehensive suite of earthquake scenarios for planning, mitigation, loss estimation, and scientific investigations. The Earthquake Scenario Project (ESP), though still under development, is a forward-looking project, estimating earthquake hazard and loss outcomes as they may occur one day. For each scenario event, fundamental input includes i) the magnitude and specified fault mechanism and dimensions, ii) regional Vs30 values for site amplification, and iii) event metadata. As a result of the ShakeMap/HAZUS demonstration projects completed for Washington and Utah, we developed a Standard Operating Procedure (SOP) for producing 12 standardized loss mapping templates we call "Priority Maps". These maps and associated tables help translate earthquake loss information to support a broad range of emergency management activities. The SOP includes step by step instructions with standardized map templates, symbology and terminology.

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Earthquake Scenario Project (ESP) Plan Overview

A grid of standard ShakeMap ground motion parameters (PGA, PGV, and three spectral response periods) is produced using the well-defined, regionally-specific approach developed by the U.S. Geological Survey (USGS) National Seismic Hazard Mapping Project (NSHMP) (Wald and others, 2009), including recent advances in empirical ground motion predictions (e.g., the NGA relations). The framework also allows for numerical (3D) ground motion computations for specific, detailed scenario analyses. Unlike NSHMP ground motions, for ESP scenarios (Figure 1), local rock and soil site conditions and commensurate shaking amplifications are applied based on detailed Vs30 maps where available or based on topographic slope as a proxy. The scenario event set is comprised primarily by selection from the NSHMP events, though custom events are also allowed based on coordination of the ESP team with regional coordinators, seismic hazard experts, seismic network operators, and response coordinators. The event set will be harmonized with existing and future scenario earthquake events produced regionally or by other researchers. The event list includes approximate 200 earthquakes in California, 100 in Nevada, dozens in each of New Mexico, Utah and Wyoming, and a smaller number in other regions. Systematic output will include all standard ShakeMap products, GIS, KML, and XML files used for visualization, loss estimation, ShakeCast (Wald and others, 2008), Prompt Assessment of Global Earthquakes for Response (PAGER), and for other systems. Integration with Hazards U.S. (HAZUS) will be a result of the creation of the HAZUS formatted input as described by Kircher and others (2006). All products will be delivered via the USGS web pages in a user-searchable archive. In addition, we aim to duplicate most of the real-time earthquake event web page functionality (Figure 2) for scenario drills and exercises, including all standard post-earthquake information tools. Hence, for each event, USGS PAGER runs will be produced, providing population exposure at current population levels, and FEMA and its partners will produce HAZUS impact assessments. Anticipated users include FEMA, the loss modeling and insurance communities, emergency responders and mitigation planners (city, county, state, industry, utilities, corporate), the general public and the media. The Earthquake Scenario Project will also take on several pending scientific challenges related to scenario generation, including ways to include fault directivity, numerical ground motions, and ways to produce ground motion uncertainties (in addition to median peak ground motions). A parallel though less comprehensive effort is underway to produce scenarios for targeted regions and events around the globe.

Proof of concept for the USGS scenario process has been done for the Pacific Northwest. A suite of scenarios are online (ShakeMap web pages); this suite was chosen from NSHMP events and by consensus by regional science coordinators, emergency managers and other users. ShakeMaps were generated, including site effects, with the same procedures as the NSHMP computations; output grids were run thru ShakeMap to derive the full suite of ShakeMap output products.

The next step is to automate the NSHMP/ShakeMap generation process, develop web delivery (via scenario “event” pages) and content, and develop event sets for each region with the help of regional coordinators and input from regional users. Scenario data will be stored on the Archive server. Additions and modifications to the products or event page will be managed through Product Distribution Layer (PDL), so the maintenance is in the hands of the product creators. Downstream products will be considered, including full HAZUS-MH loss runs, mapping and summary results, loss computations via PAGER, and risk analyses.

Prototype Plan: Washington and Utah NEHRP Demonstration Projects

1. Determine project, task, and staff for this project.
2. Identify USGS, FEMA and State personnel, and regional network roles.
3. Determine input and formats for event page and products.
4. Determine output and formats for products, including metadata to include.
5. Scripting to automate product creation.
6. Determine step-by-step procedure for each scenario: initialize event page, run hazard code, ShakeMap, PAGER exposure and losses, and develop HAZUS suite of products described below.

Future Plan:

1. Determine order of regions
2. Working with FEMA and its partners including those receiving mitigation grants, to determine scenarios and order for each region.
3. Create timelines.
4. Develop strategy for downstream loss products.
5. Develop plan for scenarios in other countries.

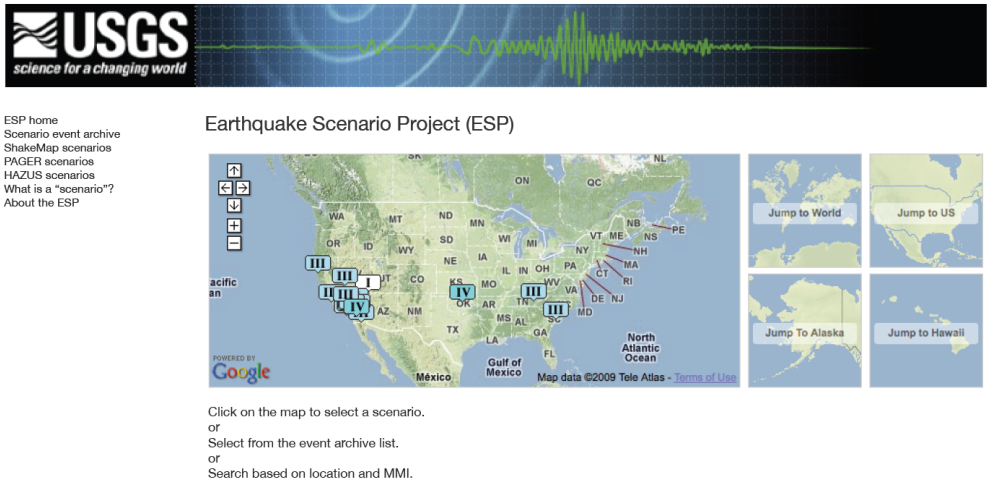


Figure 1: The project homepage will include access via map or through archive database to the library of scenarios, as well as general information on ShakeMap, PAGER and HAZUS.

Figure 2: The Scenario Event Web page is nearly identical to a regular event. Metadata includes URL links to Quaternary Fault database and scenario event information. The HAZUS loss estimation information when available will be available under the "Additional Info" tab.

NEHRP ShakeMap/HAZUS Demonstration Pilots:

Much of the work completed over the past several years in implementing pilots in Washington and Utah (Figure 3) http://www.nehrpscenario.org/?page_id=504 and more recently Nevada has tested the concept of the Earthquake Scenario Project (ESP) and points to the need for a uniform national system to provide a broad range of potential users a suite or library of credible earthquake scenarios. Frequently, the scenario selection is completed by users that want to test components of their emergency response capabilities without considering whether or not the scenario is credible. The selection of a credible scenario is especially critical for the promotion of mitigation of the vulnerabilities identified. Federal, State and local governments are unlikely to invest in mitigation if the scenarios are not considered reasonable. Deterministic scenarios based largely on the National Hazard Map sources provides a uniform method of selecting scenarios, as well as a more effective communication of the risk to a community from these sources as compared to the probabilistic approach. The ESP will also benefit from the existing ShakeMap/HAZUS interface. Through this interface the suite of ground motion maps needed for HAZUS loss estimations (PGA, PGV, 0.3 sec SA, and 1.0 sec SA) are provided and the suite of ShakeMap products that will be available in a real earthquake are produced so that users can gain valuable experience with the products prior to the event. This is especially critical for the HAZUS loss data which often get misinterpreted in the heat of a real event. Users will have familiarity with the descriptions and units used to describe building damage, social and economic losses.

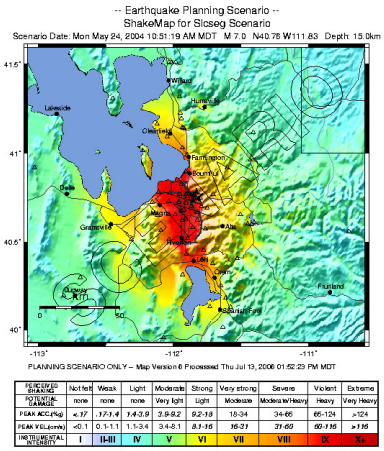
Standard Operating Procedure for the Creation of Earthquake Scenario Priority Maps using HAZUS MH MR-4 and ShakeMap

As a result of the ShakeMap/HAZUS demonstration projects (NEHRP, 2009) completed to date, we developed procedures for producing 12 standardized loss mapping templates we call "Priority Maps". These are intended to support a broad range of emergency management activities. The SOP includes step by step instructions with standardized ArcGIS templates, symbology and terminology. To ensure that all scenarios created and analyzed can be interoperable between end-users (FEMA regions, contractors, state and local governments, etc) we adopted a protocol for standard folder structure. A standard folder structure (Figure 4) ensures the functionality of a scenario and data with pre-established ArcGIS mapping templates when a project is transferred from one user to another.

HAZUS Map Templates:

To ensure interoperability and consistency we also established a standard protocol for the map layout, data symbology and spreadsheet creation. General map templates and spreadsheets are provided to support this project. The general map template files and all newly created map files for each scenario should be saved in ArcGIS with "Relative Path Names" that ensures interoperability between end-users with an established folder structure. For this Project we Developed 12 General Map Templates:

- Map 01: Direct Building Economic Loss
- Map 02: Estimated Displaced Households and Short Term Shelter Needs
- Map 03: Distribution of Elderly, Impaired Hospitals & Hospital Bed Availability
- Map 04: Electrical, Natural Gas and Oil Facility Damage
- Map 05: Estimated Building Inspection Needs
- Map 06: Estimated Concrete Debris, Steel Debris and Highway Damage
- Map 07: Demographic Distribution, Highway Damage and Hospital Functionality
- Map 08: Estimated Highway Infrastructure Damage
- Map 09: Impaired Hospitals, Hospital Bed Availability and Highway Functionality
- Map 10: Critical Water Infrastructure, Distribution and Liquefaction Susceptibility
- Map 11: Potential Search and Rescue Needs
- Map 12: Distribution of Special Needs Populations, Impaired Hospitals and Highway Functionality



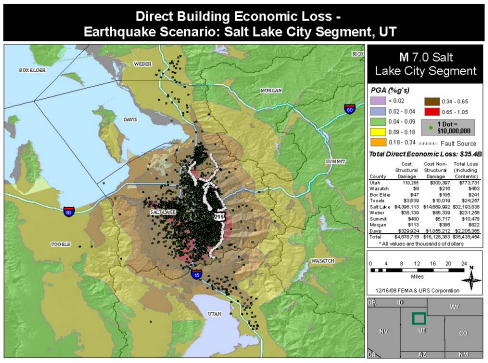


Figure 3: The completion of HAZUS estimates based on the ShakeMap supplied scenarios are displayed on a suite of 12 "priority" maps. The suite was developed over the last several years working with product users and modifying and standardizing the ArcGIS map templates.

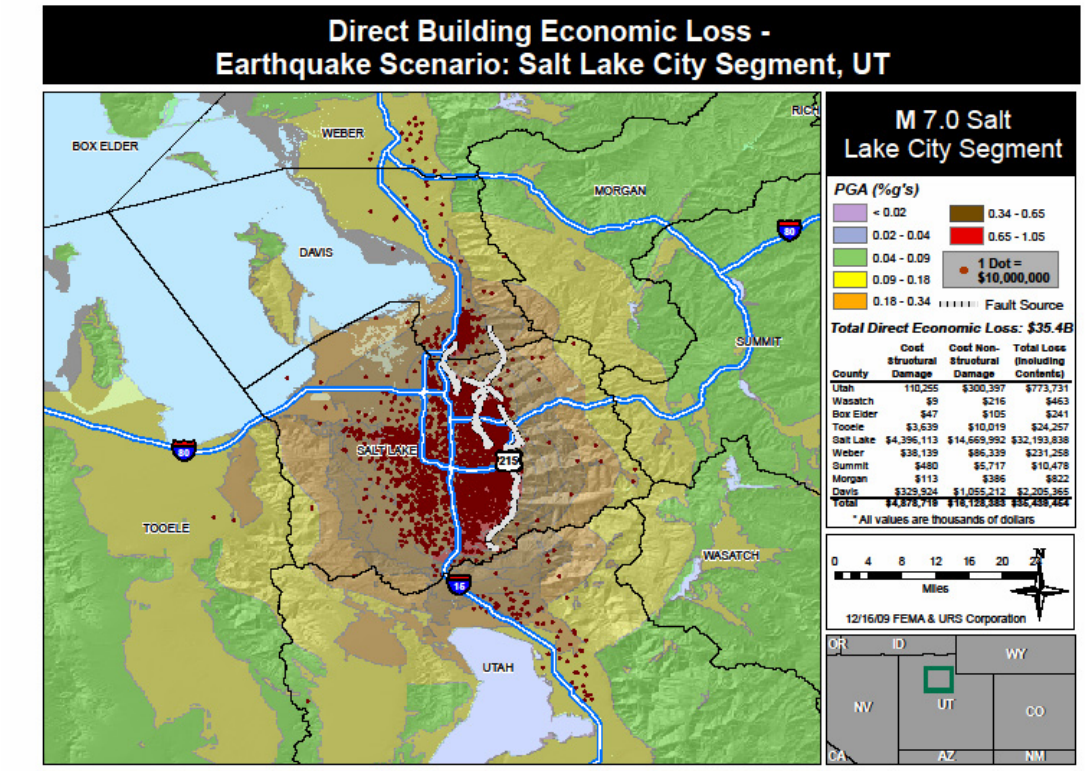
Folder Structure:

- ***ROOT DIRECTORY (C:, H:, M:, etc.)***
  - ***HAZUS_MH***
    - ***EARTHQUAKE***
      - ***TEMPLATES (Maps and Spreadsheets)***
      - ***UTAH***
        - ***UTAH_SHAKEMAPS***
        - ***UTAH_IMAGERY***
        - ***UTAH_AREA_DATA (Counties, Roads, Lakes, etc.)***
        - ***UTAH_HAZARD_DATA (Landslide, Liquefaction, etc.)***
        - ***UTAH_SCENARIOS***
          - ***SALT_LAKE_CITY_M70***
            - ***SPREADSHEETS***
            - ***SCENARIO_DATA***
            - ***MXD***
            - ***PDF***
            - ***JPEG***
            - ***SUMMARY_REPORTS***

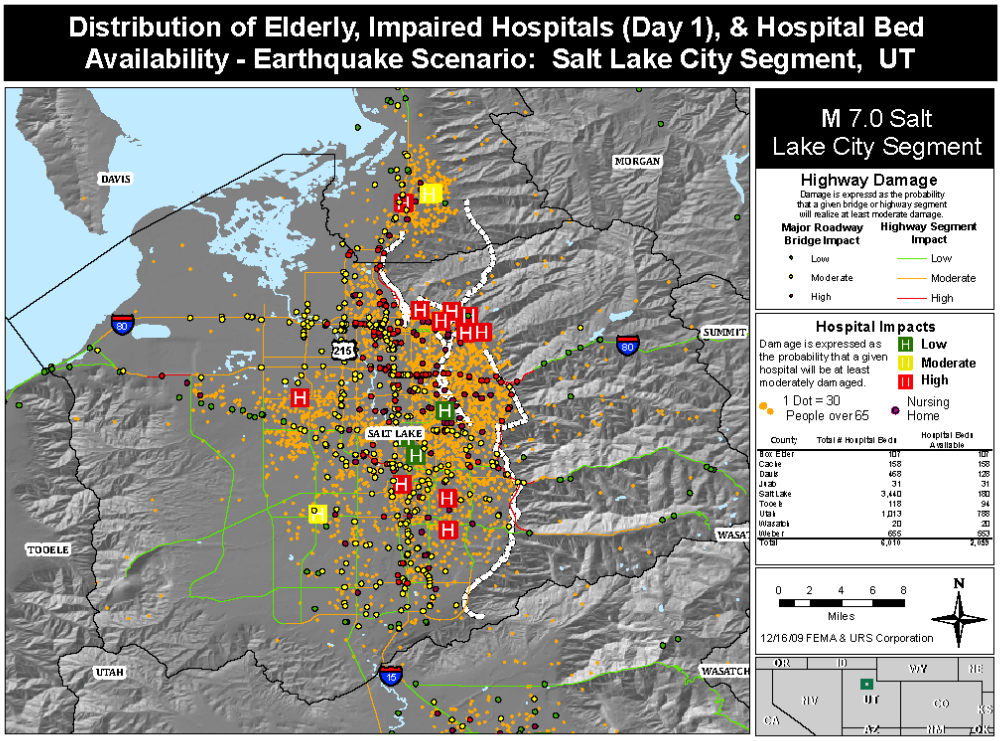
Figure 4: Data structure example is for an M7.0 scenario on the Wasatch fault underlying Salt lake City, Utah. The state name and scenario name will be different based on users' region/study area. Note we have incorporated other hazard mapping (landslide and liquefaction) that are

included in the loss estimates, as well as general base map data. In addition, a number of output formats are produced including map templates, reports and are available as .pdf and .jpg.

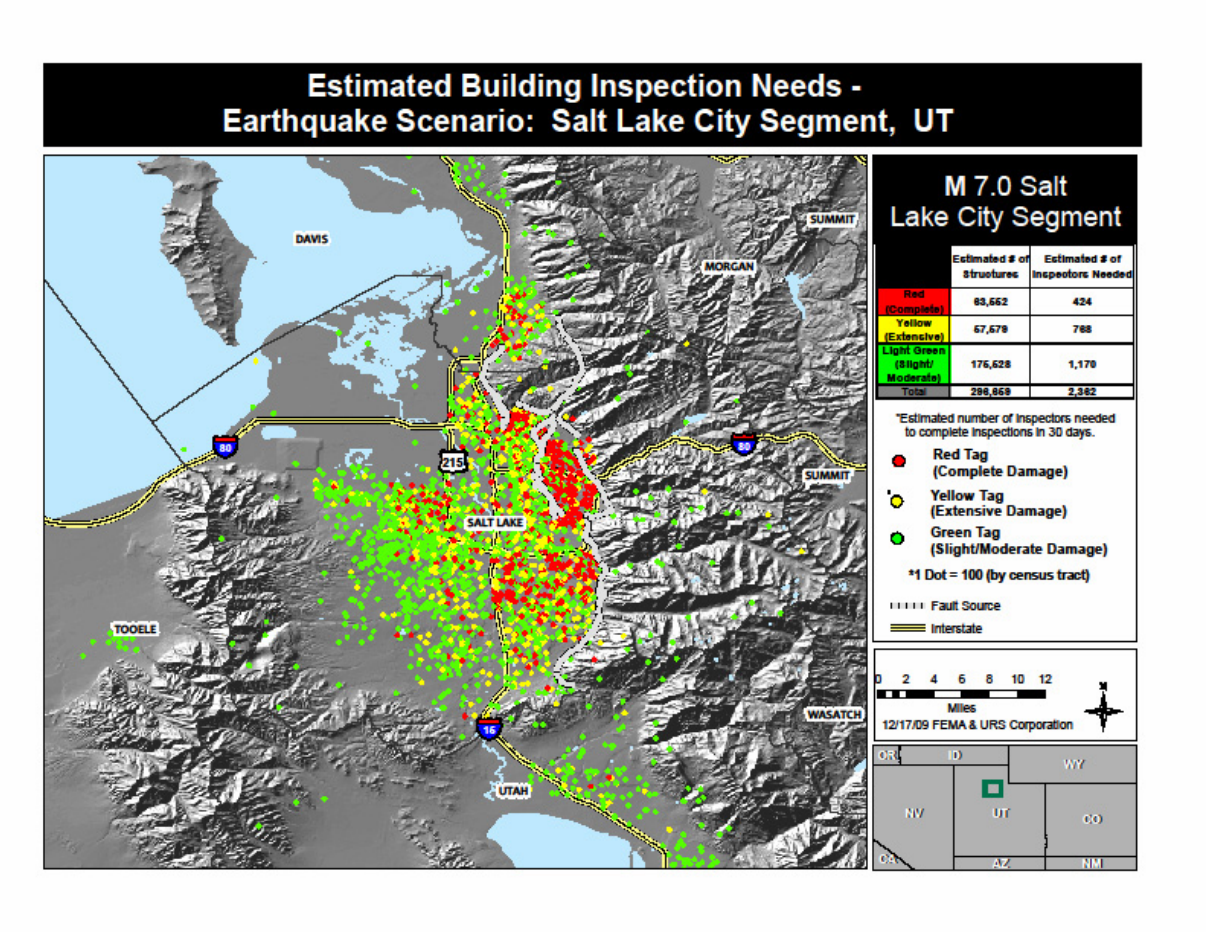
Examples of HAZUS General Map Templates (from FEMA, 2009) Created and Maintained for this Project Include –



Map 01: Direct Building Economic Loss: This map depicts an estimation of direct building economic loss that can be expected in the event of an earthquake in the study region. Note that the building economic losses are broken out into structural and non-structural categories. In U.S. earthquakes, the non-structural loss categories dominate total losses. Another note is that the economic loss results are displayed in a dot density pattern so the ground motions and other thematic data may be more clearly displayed.



Map 03: Distribution of Elderly, Impaired Hospitals & Hospital Bed Availability: This map depicts the distribution of elderly, an estimation of highway damages based on the probability that a given bridge or highway segment will realize at least moderate damage and hospital impairments based on the probability that a given hospital will be functional on day 1 in the event of an earthquake in the study region. This product helps illustrate potential transportation issues following the earthquake and the interrelationships between special needs populations and hospital locations and performance. The estimate of number of beds available after the earthquake is available from HAZUS for 1 day, 1 week, 1 month, 3 months and 1 year after the event and assists with analyzing potential gaps in bed availability when compared to the HAZUS casualty data. The estimate of bed availability does not include those that may have already been occupied prior to the earthquake.



Map 05: Estimated Building Inspection Needs: This map depicts the estimated extent of damage (complete, extensive or slight/moderate) to buildings and the number of building inspectors that would be required in the event of an earthquake in the study region. There is a critical need to inspect the safety of buildings after an earthquake. These inspections include high priority needs for shelters and other essential facilities, as well as keeping survivors out of dangerous buildings and moving them back into buildings that are safe. The purpose of this product is to analyze potential needs and gaps in the number and availability of building inspectors. Especially in significant events, a large gap may exist between the numbers of available building inspectors and the total number of building requiring inspection. FEMA provides training for the "Post-Disaster Inspection of Buildings" through the Applied Technology Council (ATC, 2005).

Conclusions

The USGS Earthquake Scenario Project (ESP) is critical in meeting the significant demand for scenarios and associated products. ESP will ensure that scenarios are developed based on authoritative sources and provide consistency with the hazard maps widely used for building codes. By integrating the project with HAZUS activities, we benefit from loss estimation products that help translate the hazard to actual impacts and risk. This includes the potential to identify vulnerabilities and develop mitigation strategies.

Since there may be hundreds of potential scenarios, a critical next step is to automate the process, including the NSHMP/ShakeMap generation process, web delivery (via scenario "event" pages) and content, and full HAZUS-MH loss runs. Pilot testing in Utah and Washington has played a critical role in developing procedures for producing the standardized loss mapping templates intended to support a broad range of emergency management activities.

Development of a Standard Operating Procedure (SOP) ensures interoperability and consistency. The SOP ensures that all scenarios created and analyzed can be interoperable between end-users (FEMA regions, contractors, state and local governments, etc). It also established a standard protocol for the map layout, data symbology and spreadsheet creation. General map templates and spreadsheets are available as part of this project

The next steps require a prioritization of work areas based on work with FEMA and its partners that support ongoing FEMA-State mitigation grant activities, as well as Catastrophic Planning and Exercises. The strategy for developing and disseminating down stream loss products requires further development, as well as automation.

References

Applied Technology Council (ATC), 2005, ATC-20-1 Field Manual: Postearthquake Safety Evaluation of Buildings: Second Edition, 159 pages, www.atcouncil.org

FEMA, 2009, ShakeMap-Based HAZUS-MH Loss Estimation Maps: Intermountain Seismic Belt, Utah: http://www.fema.gov/library/viewRecord.do?id=3660

Kircher, C.A., Whitman, R.V., and Holmes, W.T., 2006, HAZUS Earthquake Loss Estimation Methods: Natural Hazards Rev., Volume 7, Issue 2, pp. 45-59, Issue Date: May 2006

NEHRP, 2009, NEHRP's ShakeMap-HAZUS Demonstration Projects: SeismicWaves, How the National Earthquake Hazards Reduction Program Is Advancing Earthquake Safety, September 2009, http://www.nehrp.gov/pdf/SeismicWavesSep09.pdf

Wald, D. J.; Petersen, M. D.; Wald, L. A.; Frankel, A. D.; Quitoriano, V. R.; Lin, K.; Luco, N.; Mathias, S.; Bausch, D., 2009, The USGS Earthquake Scenario Project: American Geophysical Union, Fall Meeting 2009, abstract #NH51C-1066.

Wald, D.J., Lin, K.W., Porter, K., Turner, L., 2008, ShakeCast: Automating and Improving the Use of ShakeMap for Post-Earthquake Decision-Making and Response, Earthquake Spectra Volume 24, Issue 2, pp. 533-553 (May 2008)