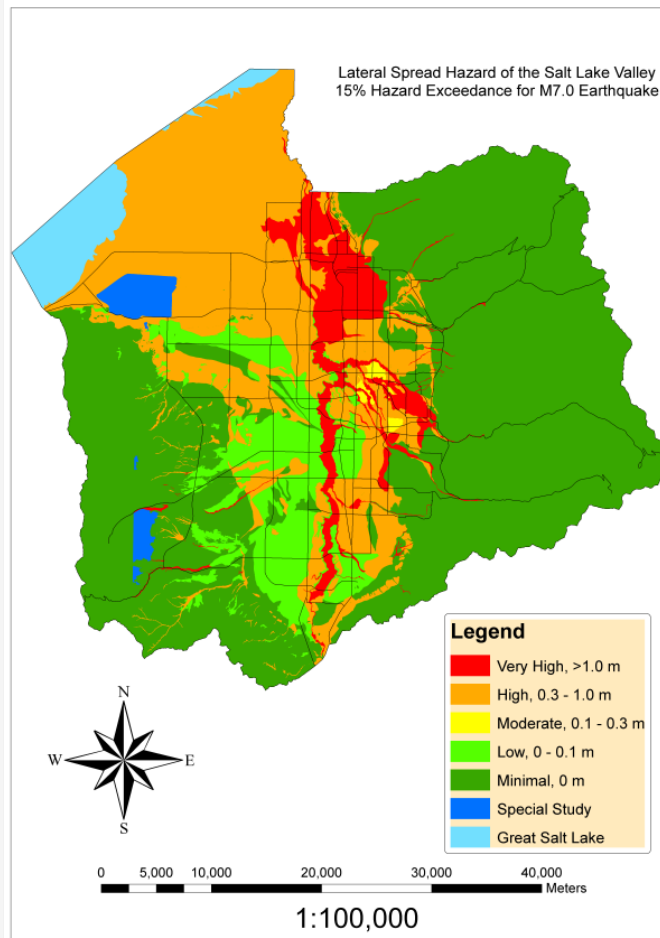


Utah Liquefaction Advisory Group (ULAG)



Probabilistic Liquefaction Hazard Mapping for Davis, Weber and Salt Lake Counties

February 12, 2018
Salt Lake City, Utah

Steven F. Bartlett, Ph.D., P.E.
University of Utah

Types of Liquefaction Displacement



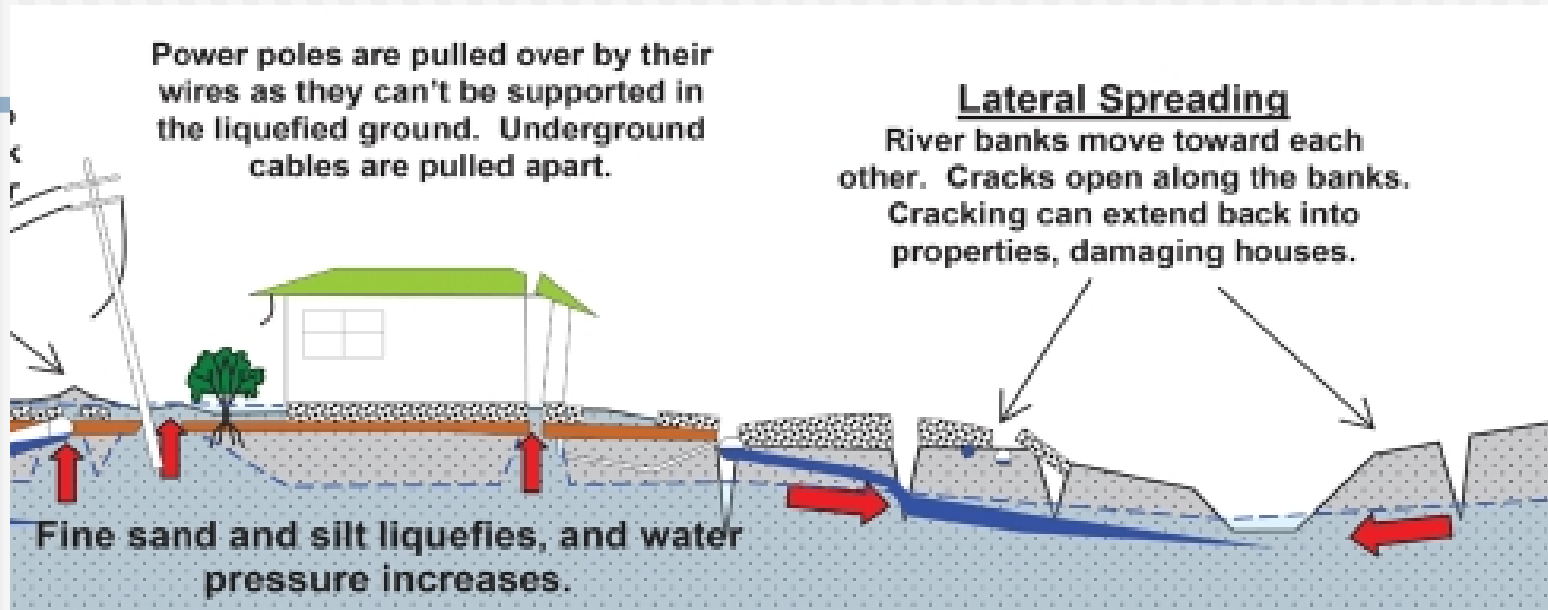
Port of Kobe,
1995 Kobe,
Japan
Earthquake

Ground Settlement



2010 Christchurch Earthquake

Types of Liquefaction Displacement



Lateral Spread



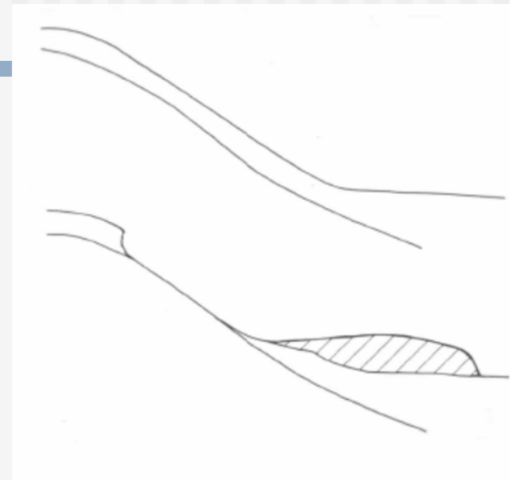
1964 Niigata, Japan Earthquake

Types of Liquefaction Displacement



Valdez, 1964
Alaska
Earthquake

Flow Failure



Seward,
1964
Alaska
Earthquake

Types of Liquefaction Hazard Maps

- Liquefaction Susceptibility Maps
- Liquefaction Potential Maps
 - Scenario Maps
 - Probabilistic-Based Maps
- Ground Failure Maps
 - Lateral Spread
 - Ground Settlement

Utah's Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 1

Develop Probabilistic Liquefaction Hazard Maps for Urban Counties in Utah

Salt Lake County

Utah County

Davis County

Weber County

Cache County

Utah's Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 1 (cont.)

Types of Maps

- (1) Liquefaction Triggering Maps
- (2) Lateral Spread Displacement Hazard Maps
- (3) Liquefaction-Induced Ground Settlement Maps

Utah's Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 2

Develop ARC GIS Programs for Implementing Probabilistic Mapping Procedures for Other Regions in U.S.

- **Strong ground motion hazard estimates from PSHA and National Strong Motion Mapping Program**
- **User methods based on ArcGIS algorithms**

Utah's Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 3

Establish and Populate a Subsurface Geotechnical Database for Public Use

- **Geotechnical Evaluations**
- **Land Use Planning**
- **Research**
- **Potential Partners**
 - **UDOT**
 - **Salt Lake County and Cities**

Utah's Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 4

Education and Public Outreach

- **User Friendly Maps**
- **Assist Counties in Implementation and Ordinances**
- **Outreach Seminars and Website**

Previous Work

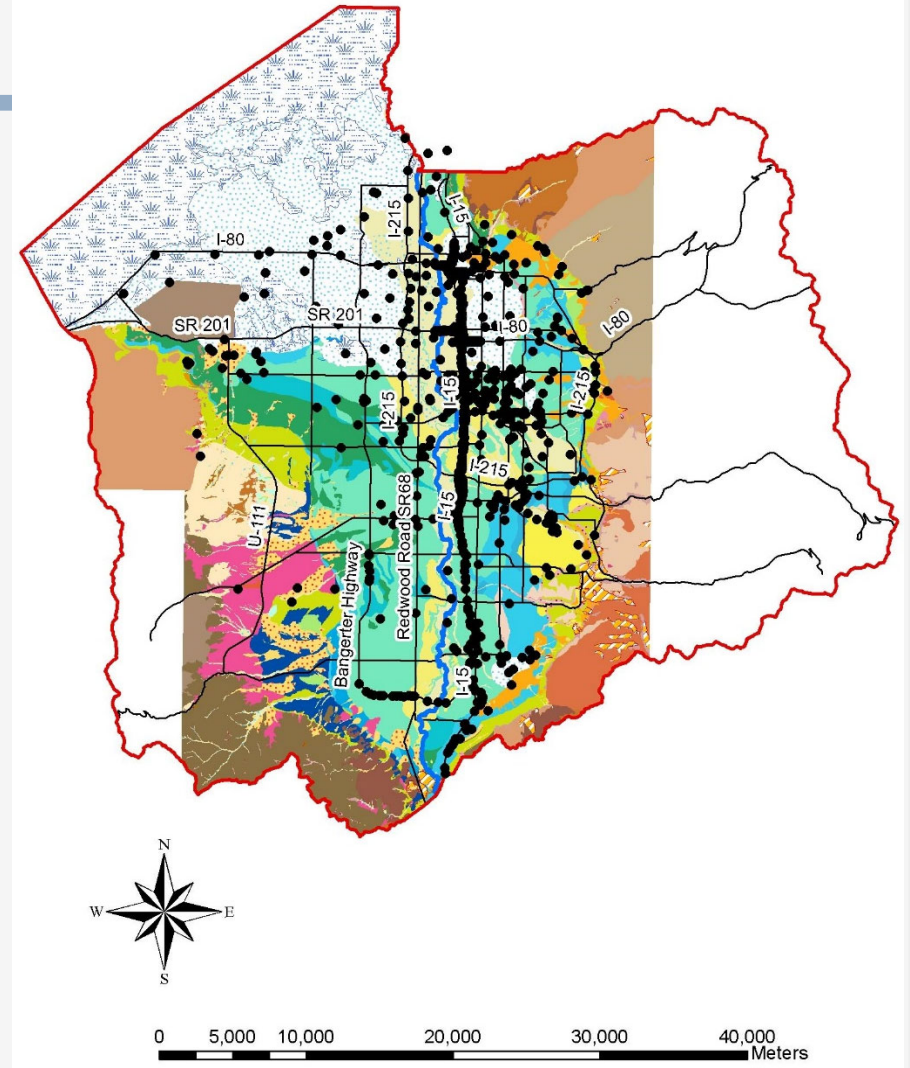
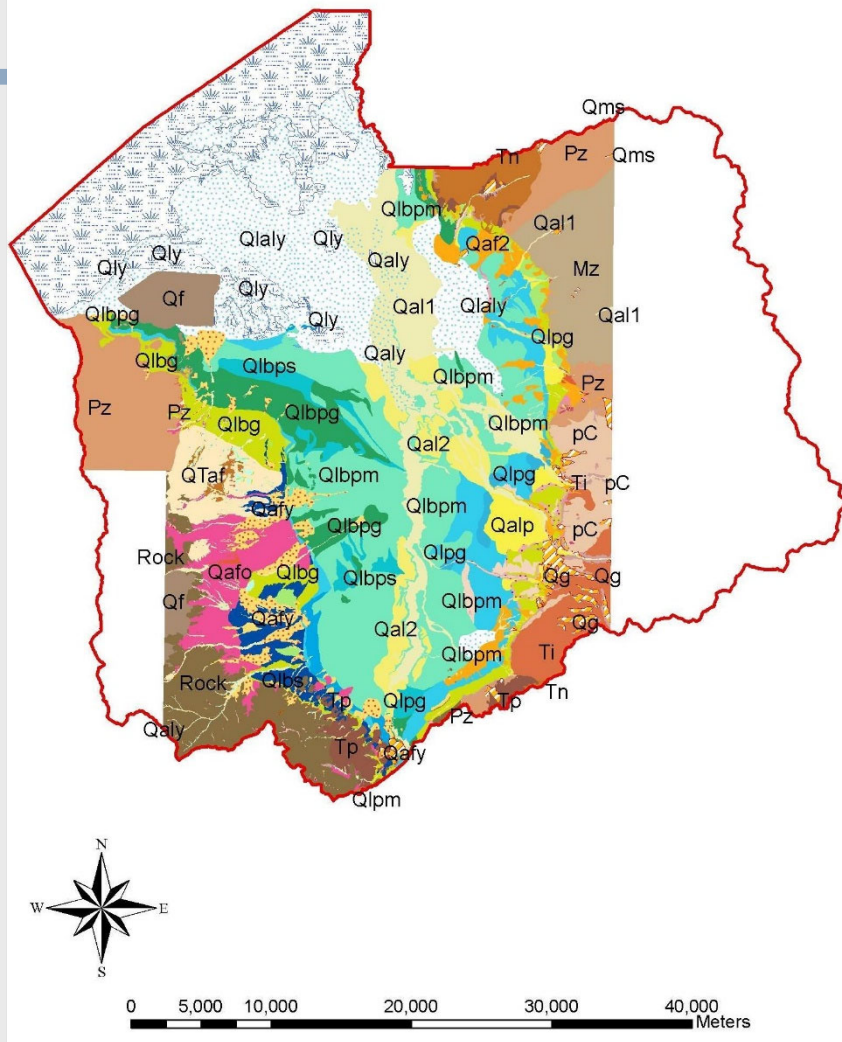
FY 2004

- **Geotechnical Database (N. Salt Lake Co.)**
- **M7.0 lateral spread displacement hazard map (N. Salt Lake Co.) published in *Earthquake Spectra*.**

FY 2005

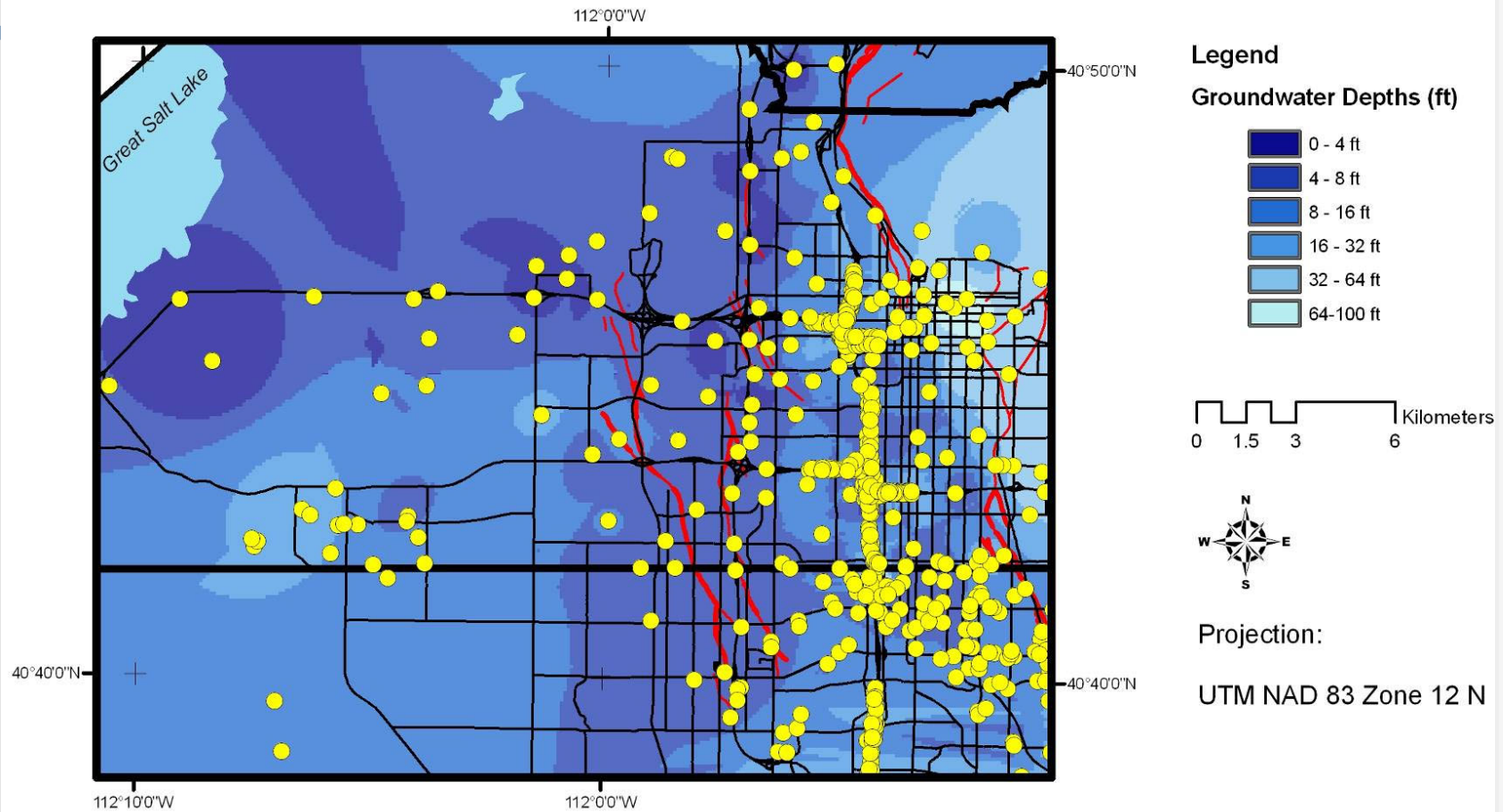
- **Geotechnical Database (S. Salt Lake Co.)**

Mapping Inputs



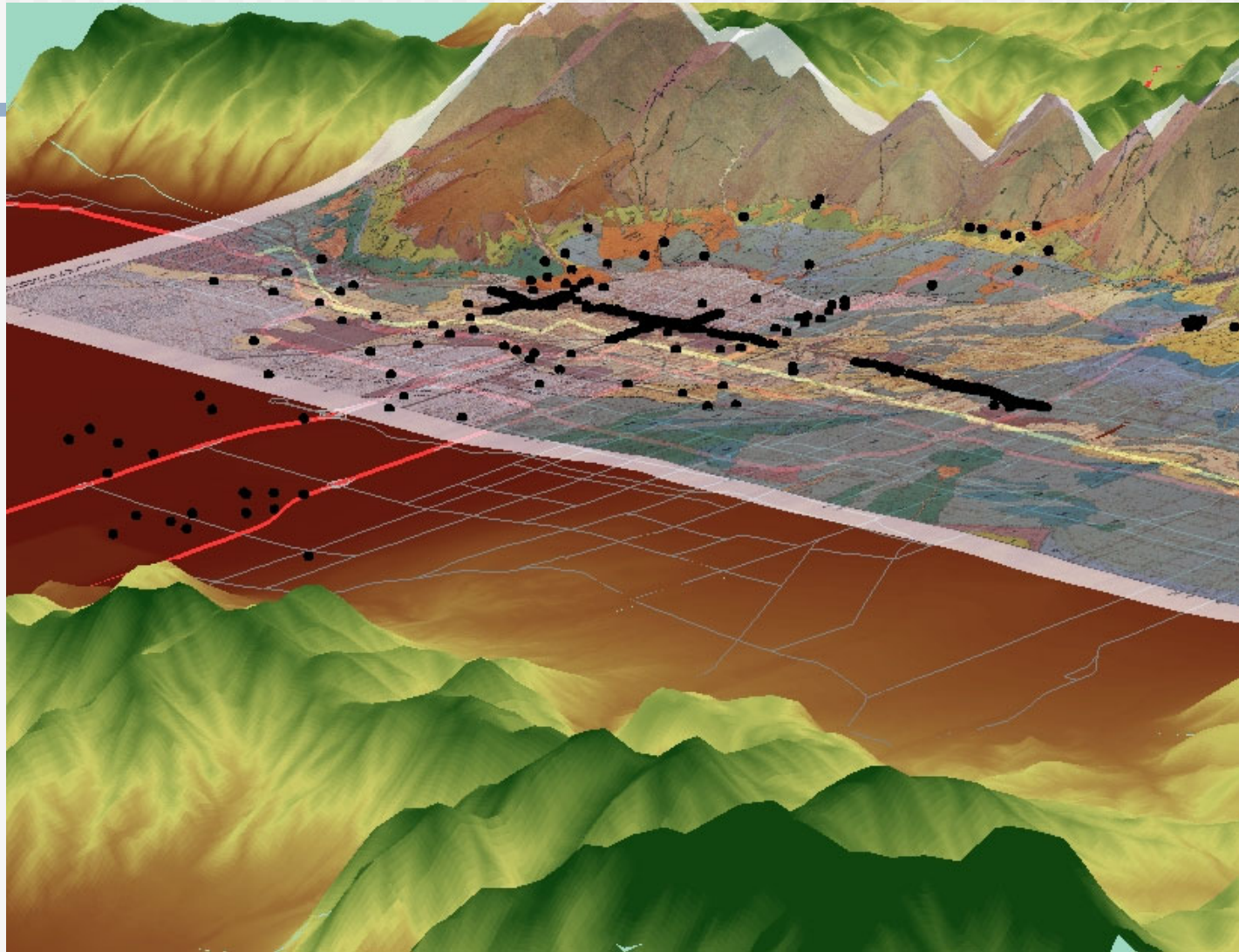
Geologic Man

Mapping Inputs



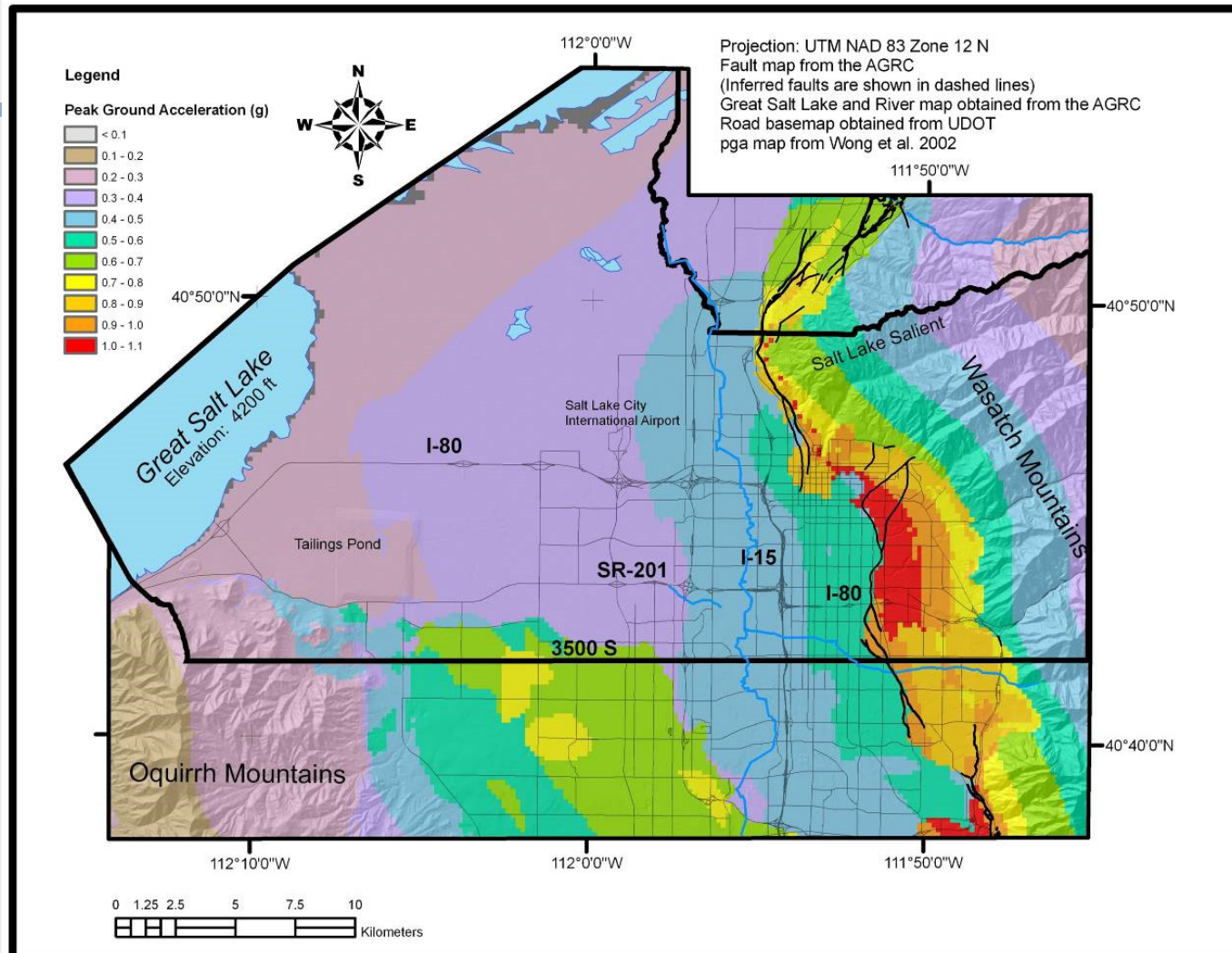
Groundwater Depth Map

Mapping Inputs



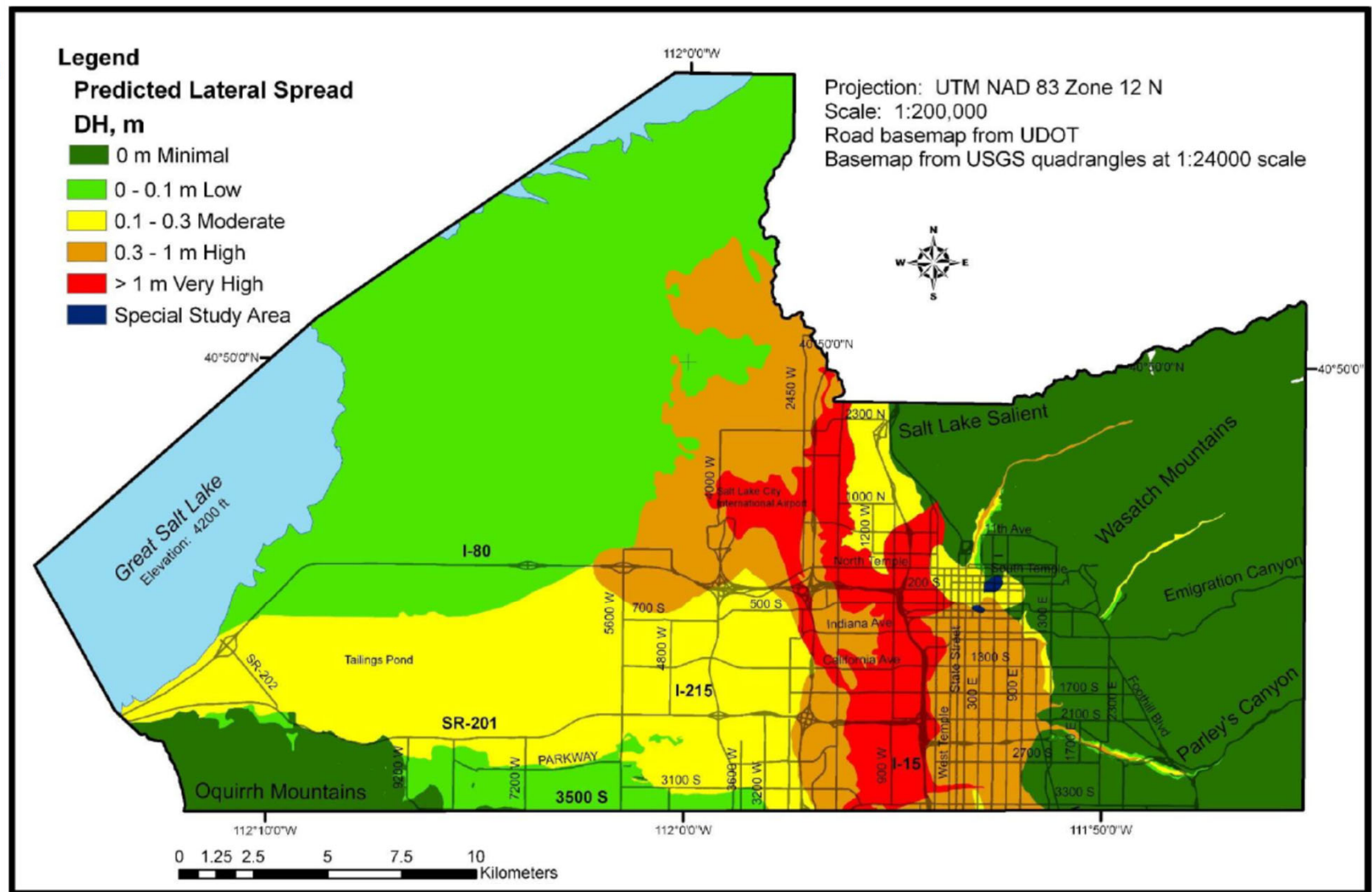
Digital Elevation Model

Mapping Inputs

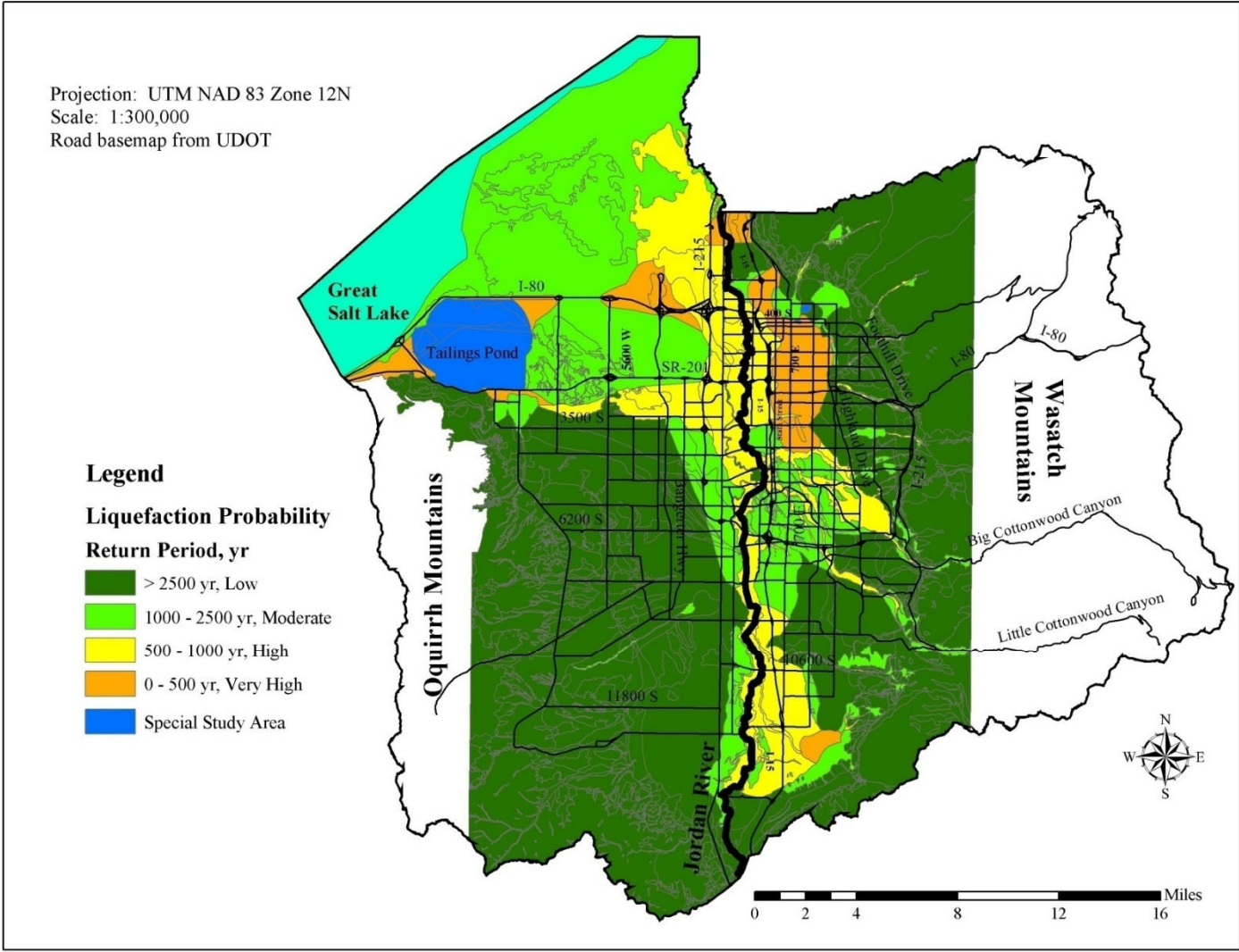


Estimates of peak ground acceleration (Wong et al., 2002)

Lateral Spread Displacement Hazard – N. Salt Lake Co.



Probabilistic liquefaction potential map Salt Lake Co. – (2002 USGS Input)



Previous Work

FY 2006 & 2007

2.1.1	7
Task 1: Development of CPT and SPT correlations (University of Utah).....	7
2.1.2 Task 2: Correlation of Subsurface Geologic and Geotechnical ArcGIS™ Database with Surficial Geologic Mapping (Utah Geological Survey)	8
2.1.3 Task 3: Mapped mean annual probability of triggering liquefaction for southern Salt Lake County (University of Utah)	8
2.1.4 Task 4: Mapped probability of triggering liquefaction for a scenario earthquake for Salt Lake County (University of Utah)	8
2.1.5 Task 5: Mapped mean annual probability of lateral spread exceeding displacement thresholds of 0.1, 0.3 and 1.0 meters for northern Salt Lake County (University of Utah).....	9
2.1.6 Task 6: Mapped lateral spread horizontal displacement for a scenario event for northern Salt Lake County (University of Utah)	9
2.1.7 Task 7: Synthesis report of seismically induced ground displacement in Salt Lake County (University of Utah, Simon-Bymaster, Inc., and Utah Geological Survey)	9
2.1.8 Task 8: CPT subsurface investigations in downtown Salt Lake City (University of Utah and ConeTech)	12
2.1.9 Task 9: Map production and report delivery (University of Utah and Utah Geological Survey)..	12

Previous Work

FY 2006 – 2007 (cont.)

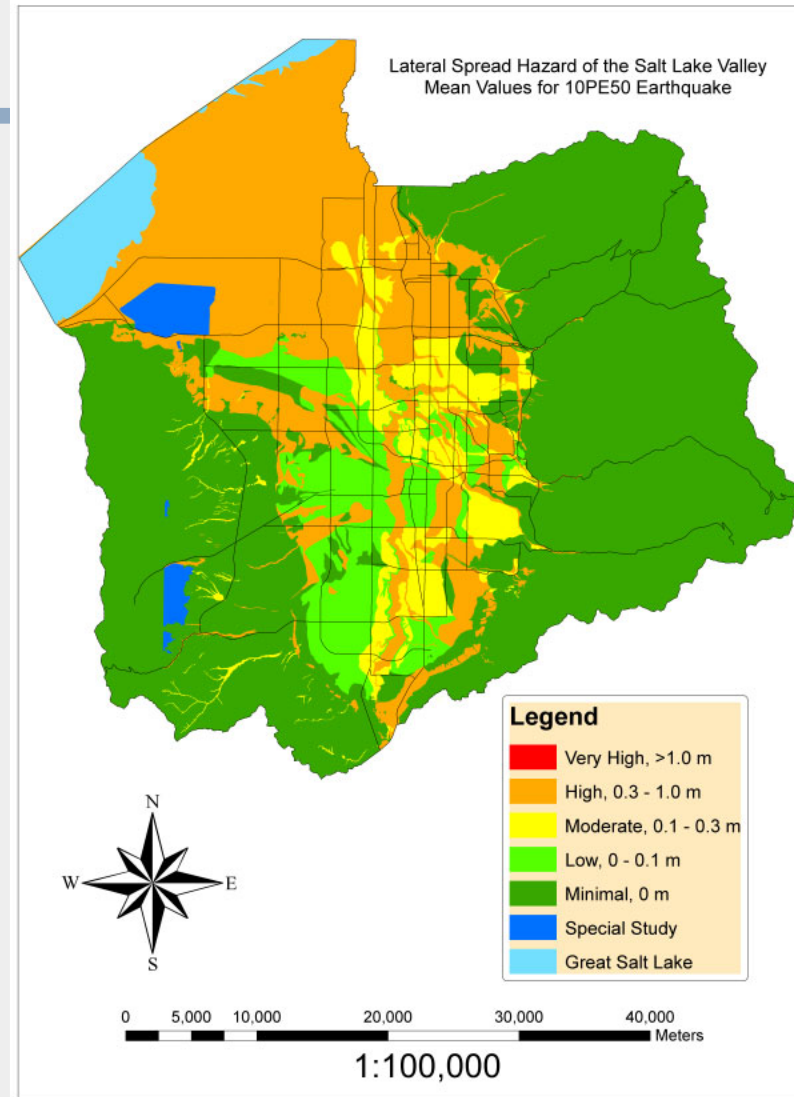
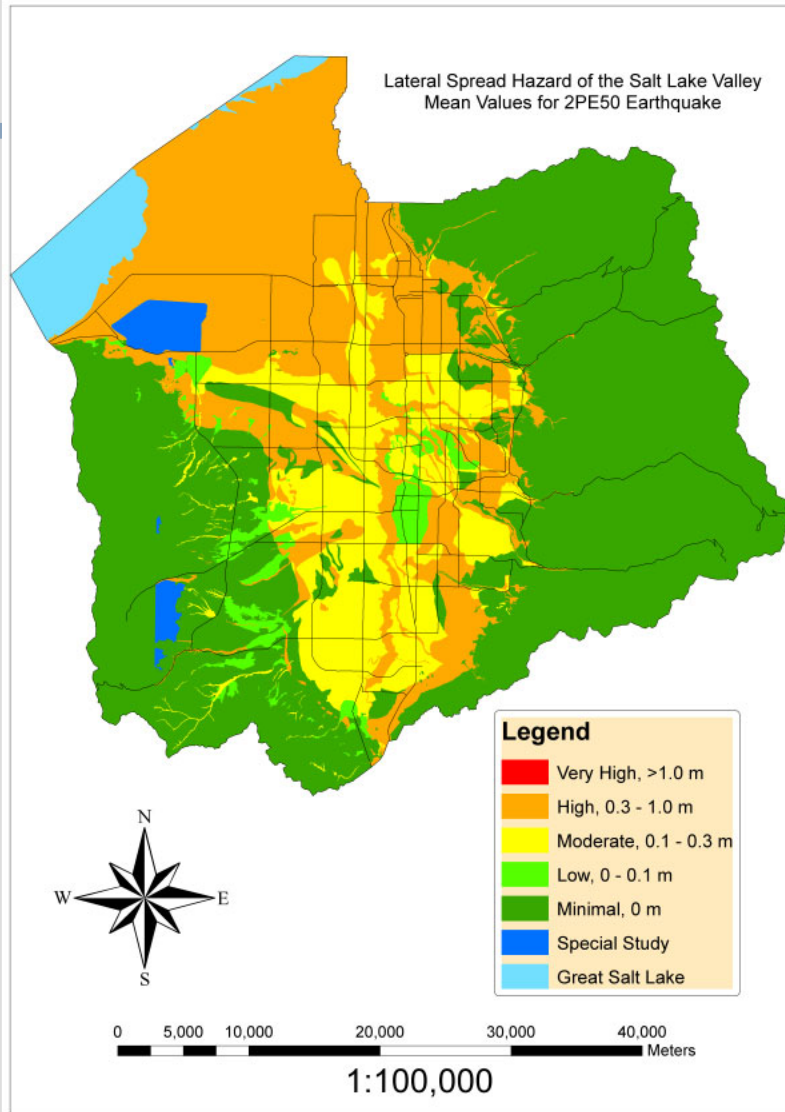
2.1 Methods and Tasks – Phase IV, FY 2007	8
2.1.1 Task 1: Collection and preliminary geologic analysis of surface and subsurface data to identify data gaps and data-collection requirements for future hazard mapping efforts in Utah Valley (Brigham Young University, University of Utah, Utah Geological Society).....	9
2.1.2 Task 2: Completion of probabilistic lateral spread hazard maps and deterministic lateral spread hazard map for a scenario earthquake for southern Salt Lake County (University of Utah).....	10
2.1.3 Task 3: Development of liquefaction-induced settlement map for Salt Lake County (Brigham Young University, University of Utah).	10
2.1.4 Task 4: Map production and report delivery (University of Utah, Brigham Young University and Utah Geological Survey).....	10

FY 2008 (No Funding)

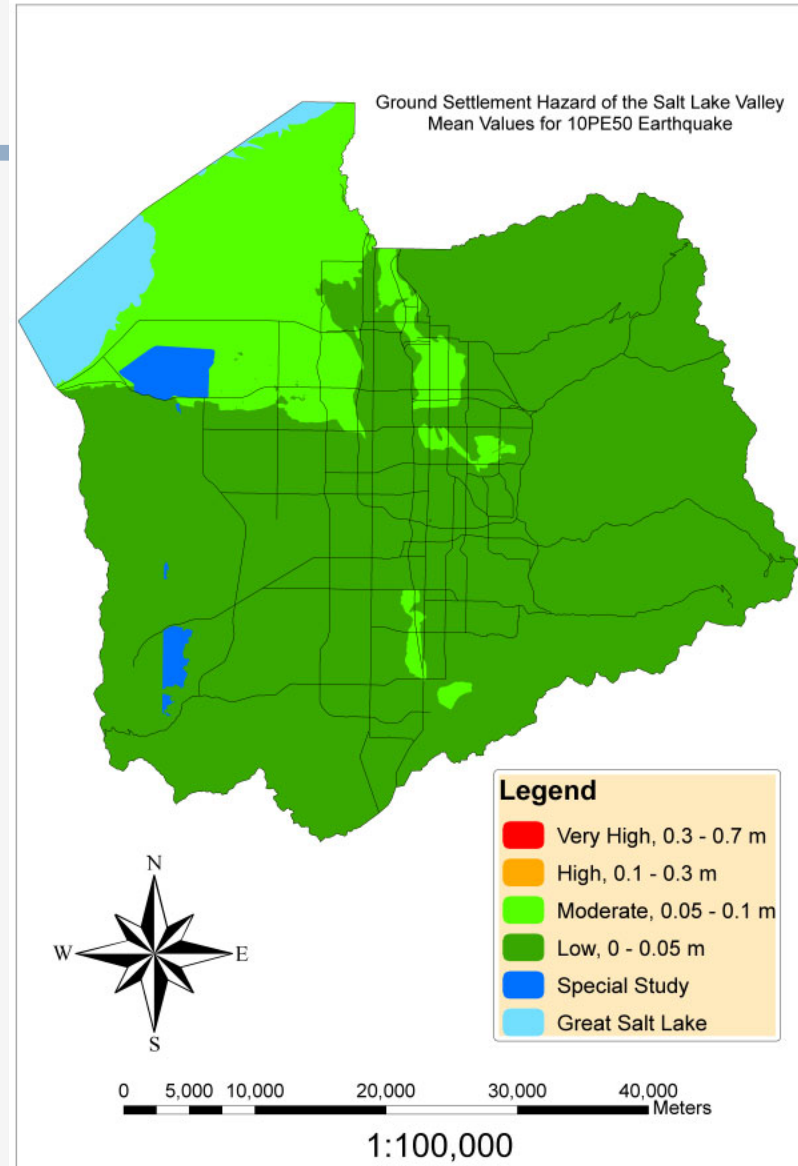
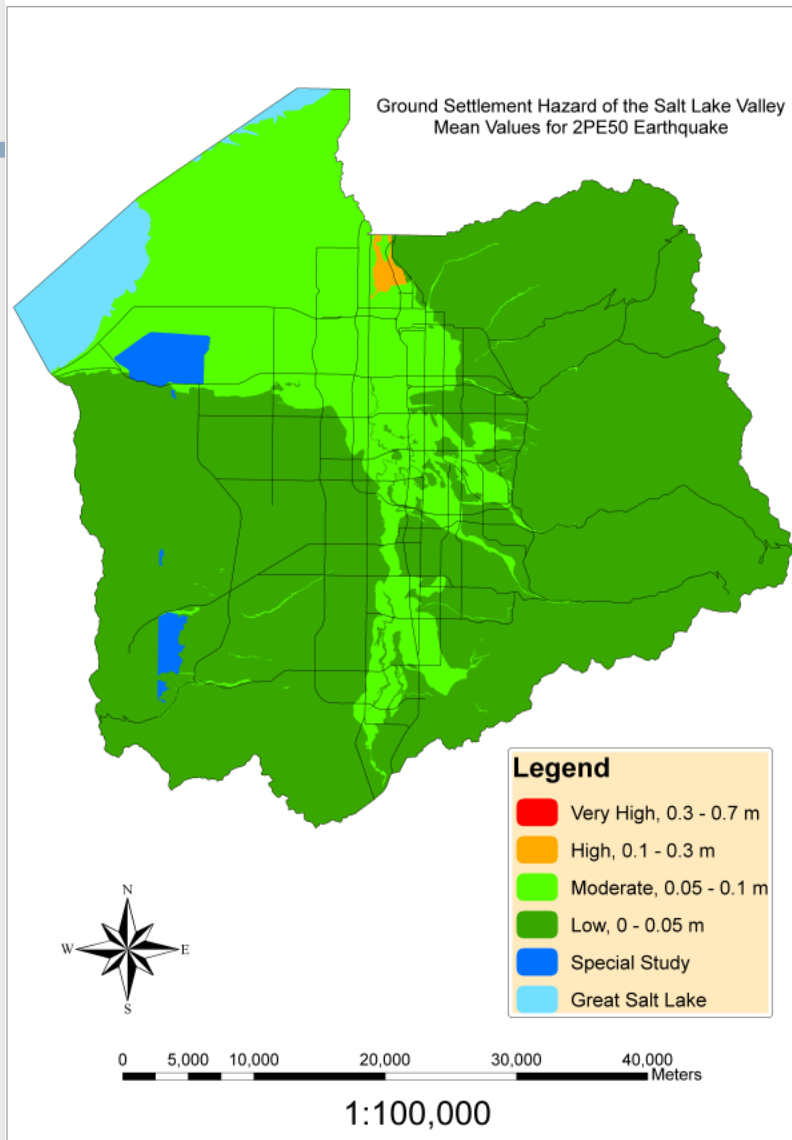
FY 2009 (No Funding)

FY 2010 (No Funding)

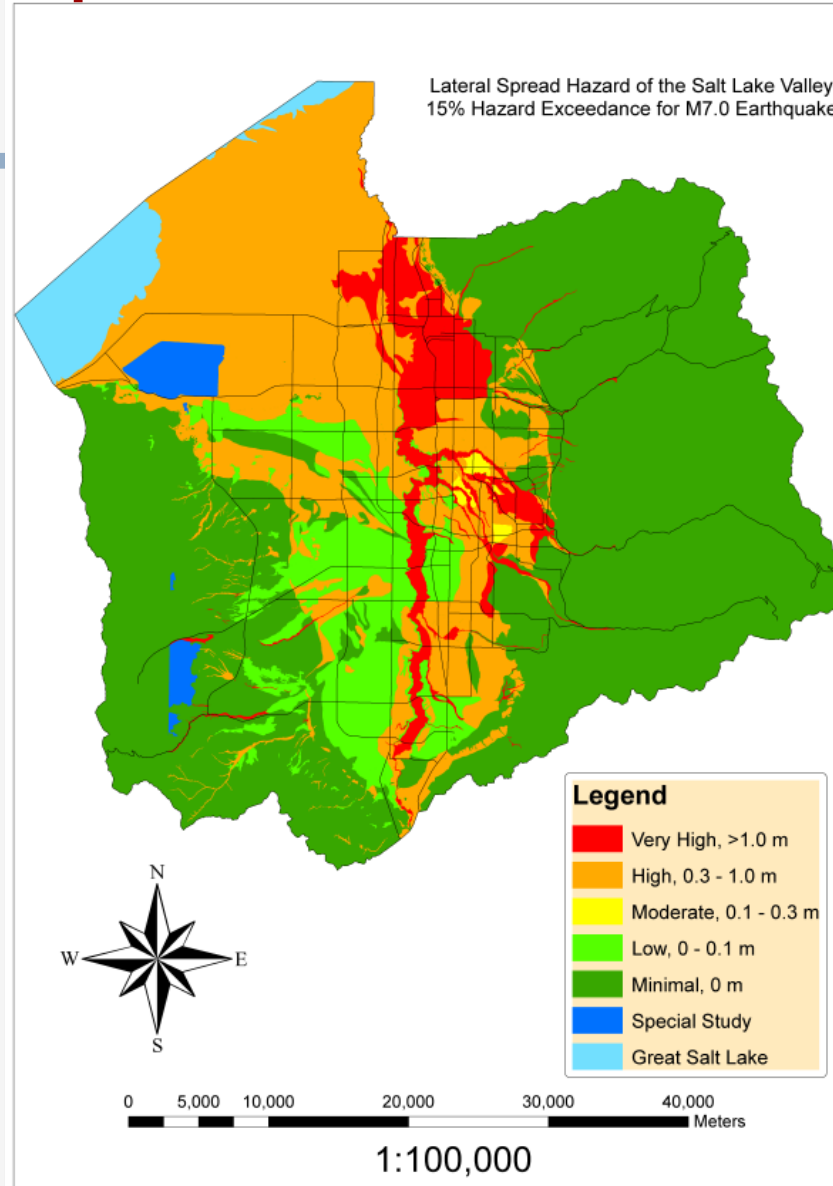
Probabilistic liquefaction potential maps for 2500 and 500-year return periods



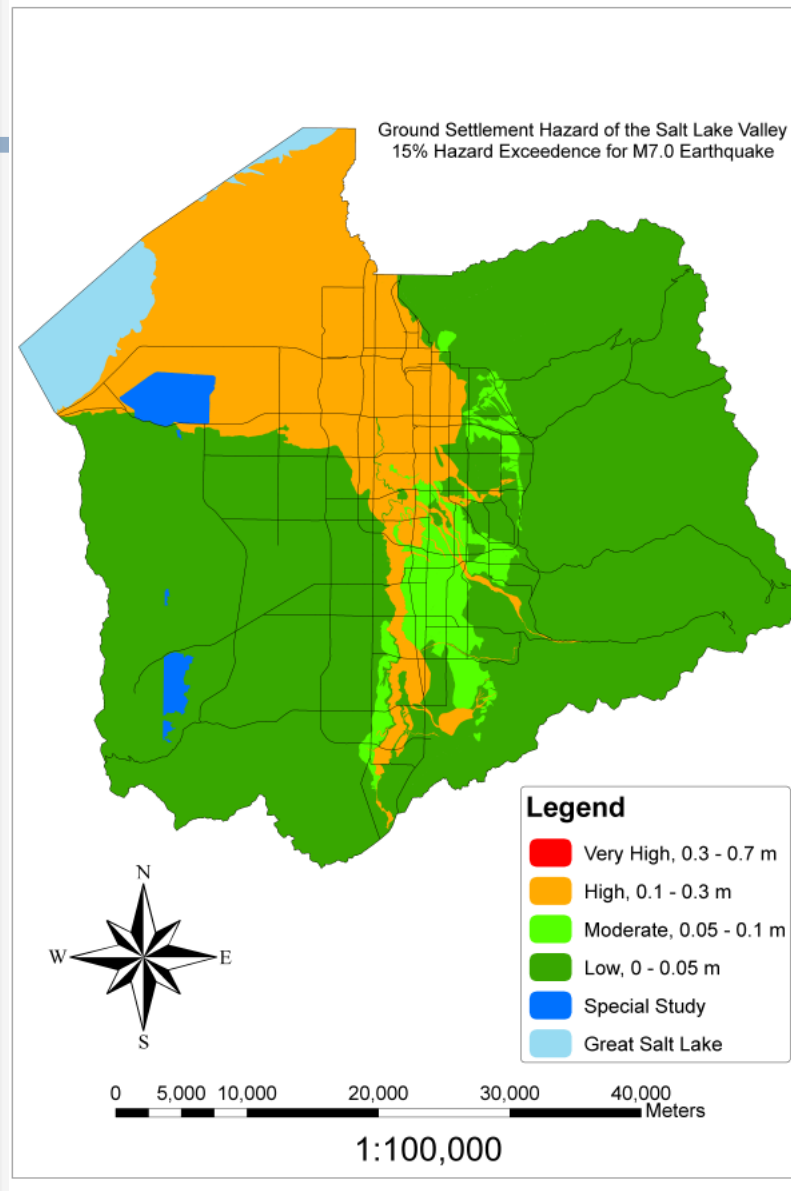
Probabilistic ground settlement maps for 2500 and 500-year return periods



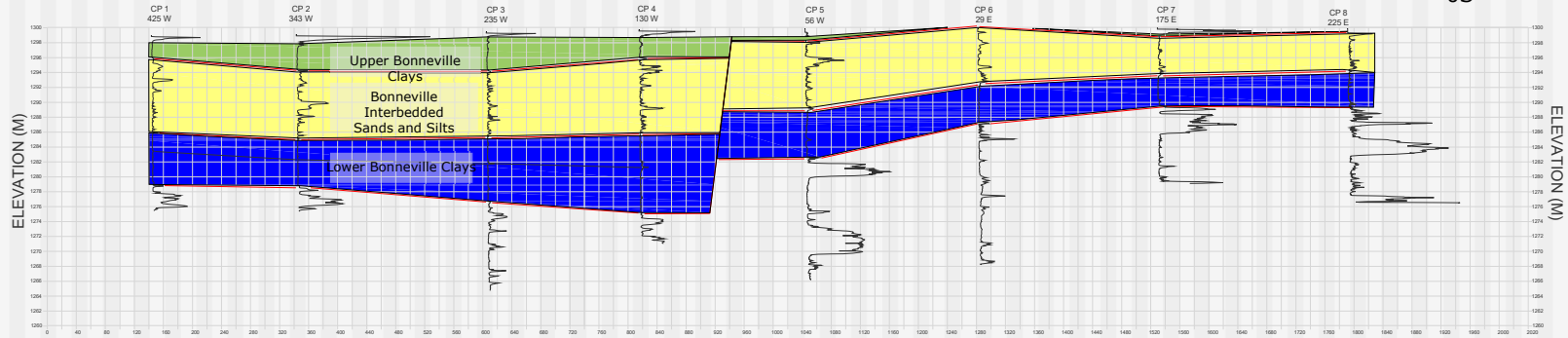
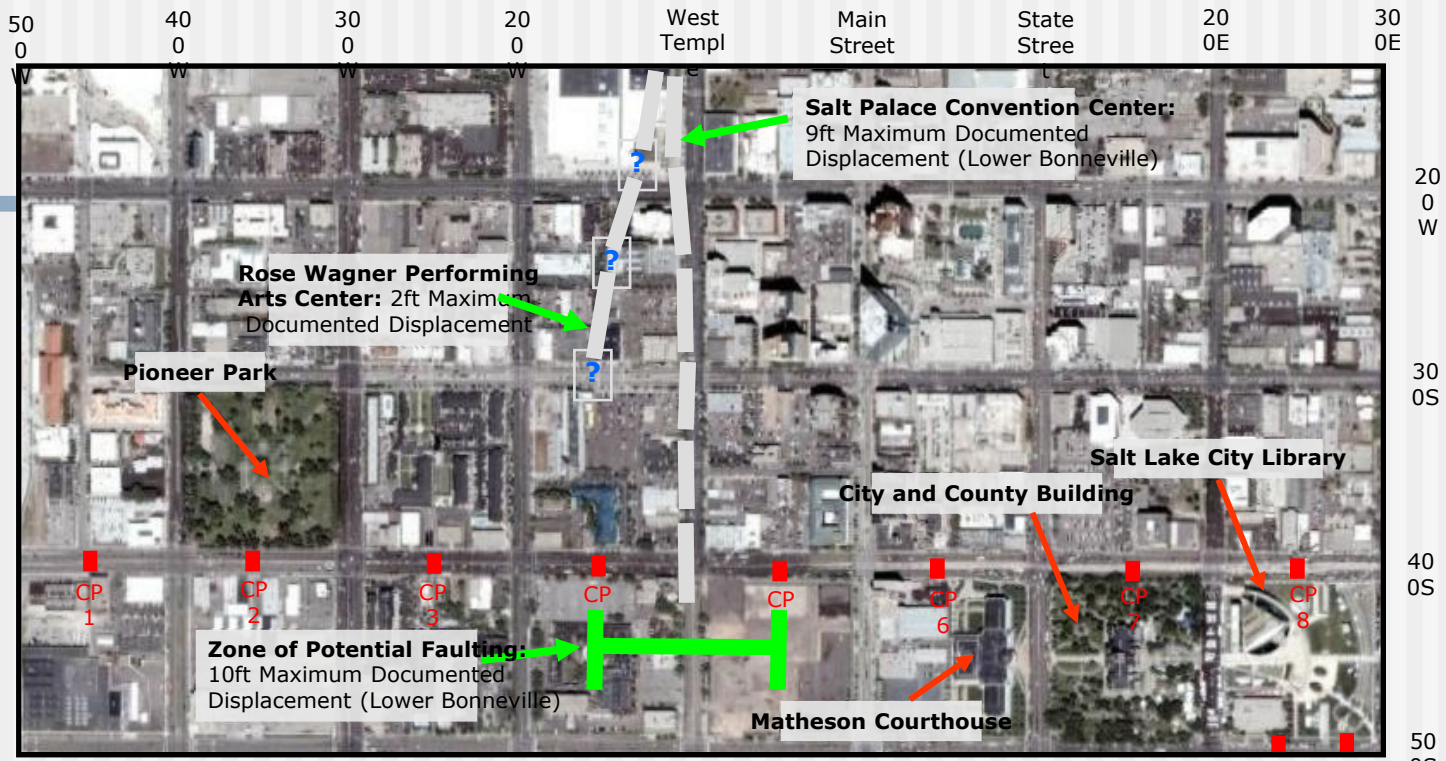
M 7.0 Lateral spread displacement map 15 percent chance of exceedance



M 7.0 ground settlement map 15 percent chance of exceedance



Downtown Displacement Investigations



Possible Extension of the Warm
 Approximate
 ■ Approximate CPT Sounding Locations

Previous Work

FY 2008 (No Funding)

FY 2009 (No Funding)

FY 2010 (No Funding)

FY 2010 (Partial Funding from WBWCD for Mapping Weber Co.)

FY 2011 (USGS –Funding for Mapping Weber Co.)

Weber County Liquefaction Hazard Mapping

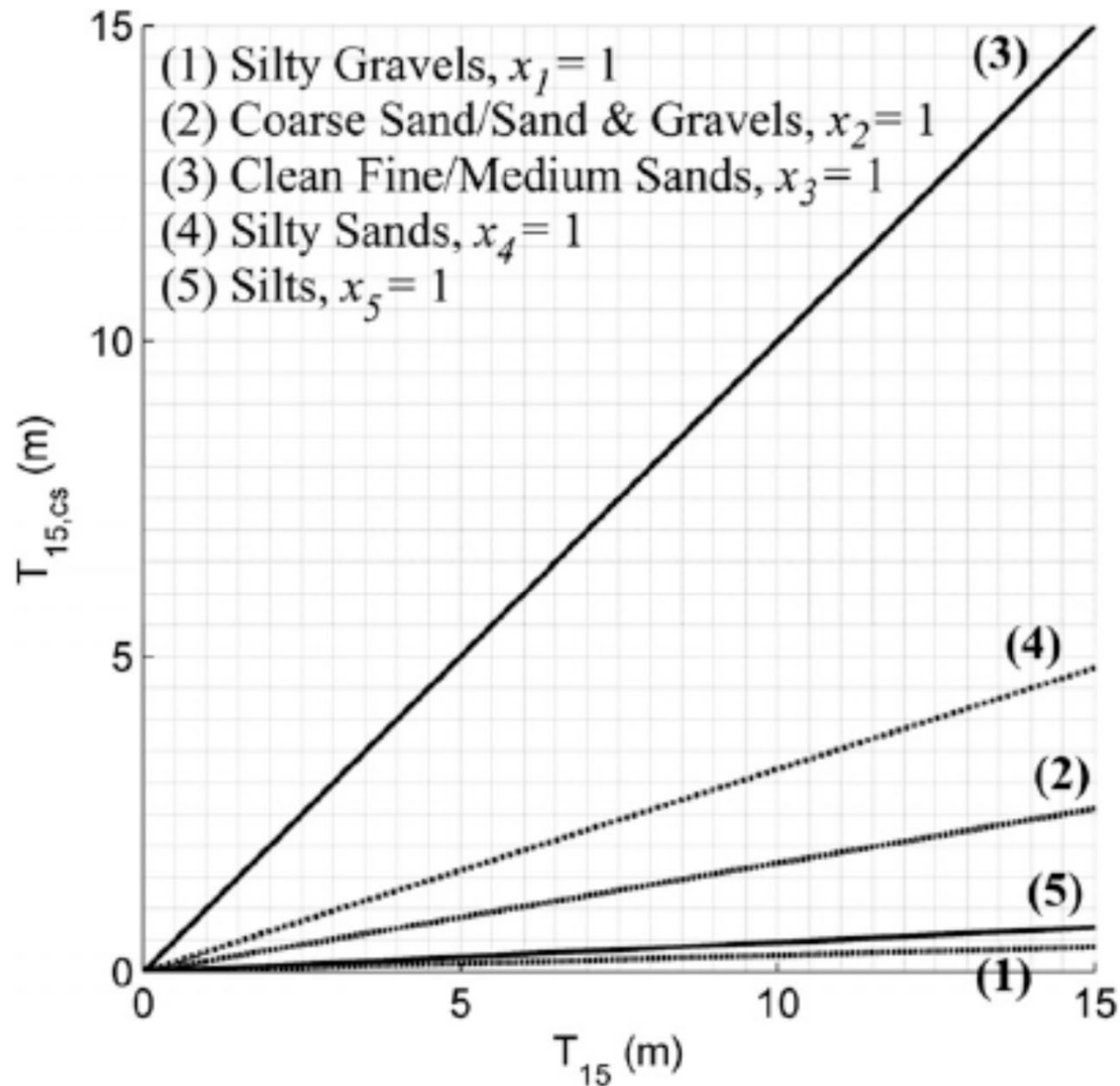


Fig. 3. T_{15} versus $T_{15,cs}$ according to soil index

Weber County Liquefaction Hazard Mapping

$$\text{Log}D_H = b_o + b_{off}\alpha + b_1M + b_2\text{Log}R^* + b_3R + b_4\text{Log}W + b_5\text{Log}S + b_6\text{Log}T_1 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5$$

$$\overline{\text{Log}(D_H)} = \left(\begin{array}{l} -8.453 + 1.348 \cdot M_w - 1.068 \cdot \text{Log}(R^*) - 0.017 \cdot R + 0.334 \cdot \text{Log}(S) + \\ + 0.588 \cdot \text{Log}(T_{15,cs}) + 0.278 \end{array} \right) \quad (4.2)$$

$$\overline{\text{Log}(D_H)} = \left(\begin{array}{l} -8.795 + 1.348 \cdot M_w - 1.068 \cdot \text{Log}(R^*) - 0.017 \cdot R + 0.453 \cdot \text{Log}(W) + \\ + 0.588 \cdot \text{Log}(T_{15,cs}) + 0.278 \end{array} \right) \quad (4.3)$$

Weber County Liquefaction Hazard Mapping

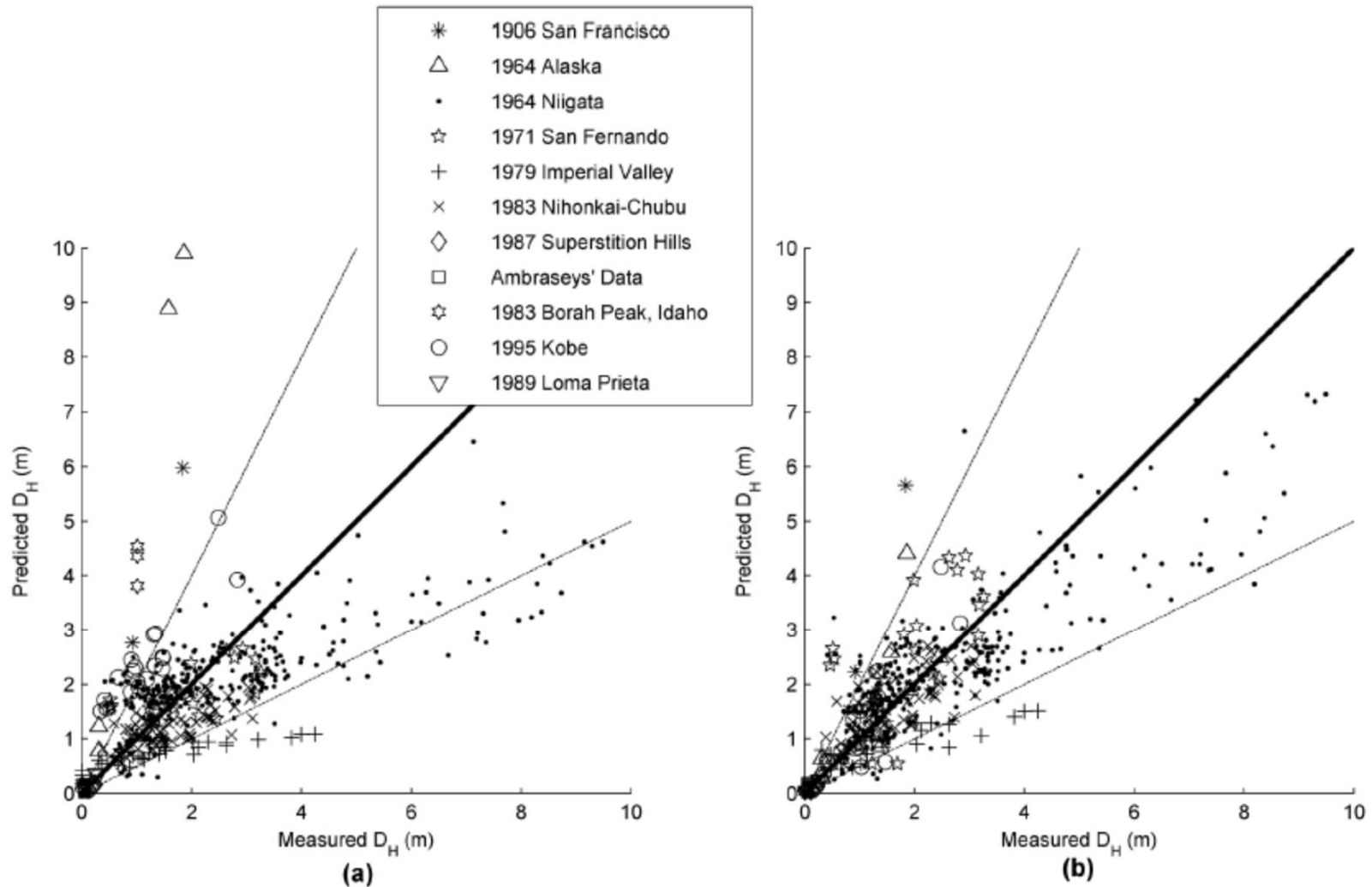


Figure 3.1. Predicted lateral spread displacement using (a) eqn. (3.3), or (b) eqn. (3.4), versus measured lateral spread displacement from the case history database of Youd et al., 2002

Weber County Liquefaction Hazard Mapping

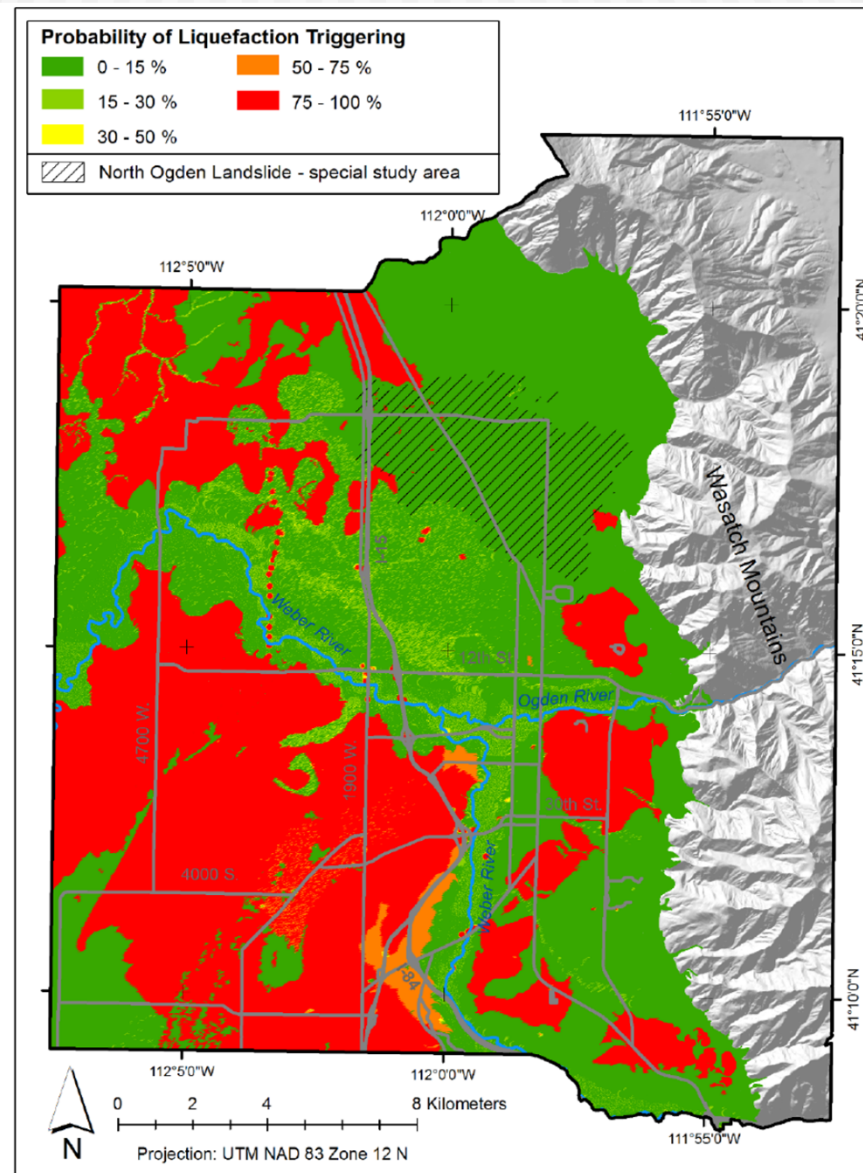


Figure 5.4. 50th percentile probabilities of liquefaction triggering given a 500-year seismic event; Weber County, Utah

Weber County Liquefaction Hazard Mapping

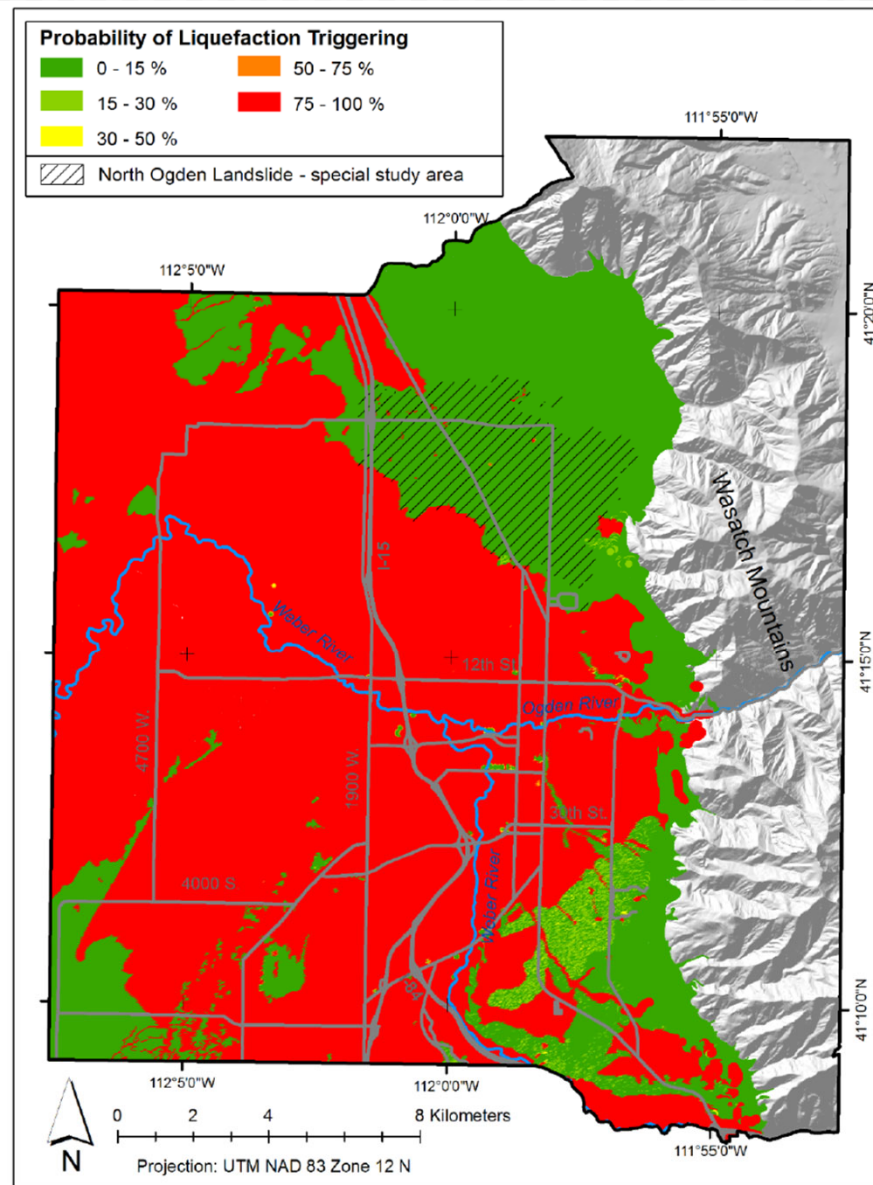


Figure 5.5. 50th percentile probabilities of liquefaction triggering given a 2,500-year seismic event; Weber County, Utah

Weber County Liquefaction Hazard Mapping

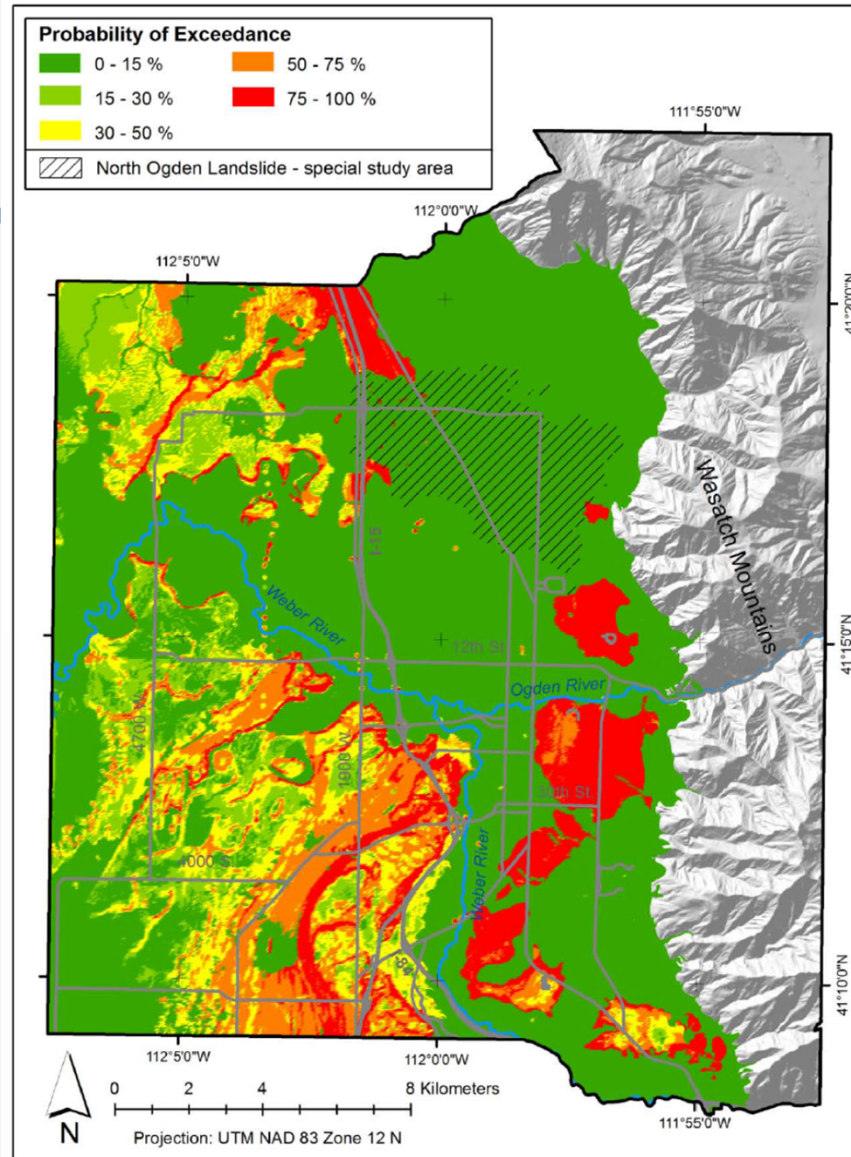


Figure 5.6. 50th percentile probabilities of lateral spread displacement exceeding 0.1 meters given a 500-year seismic event; Weber County, Utah

Weber County Liquefaction Hazard Mapping

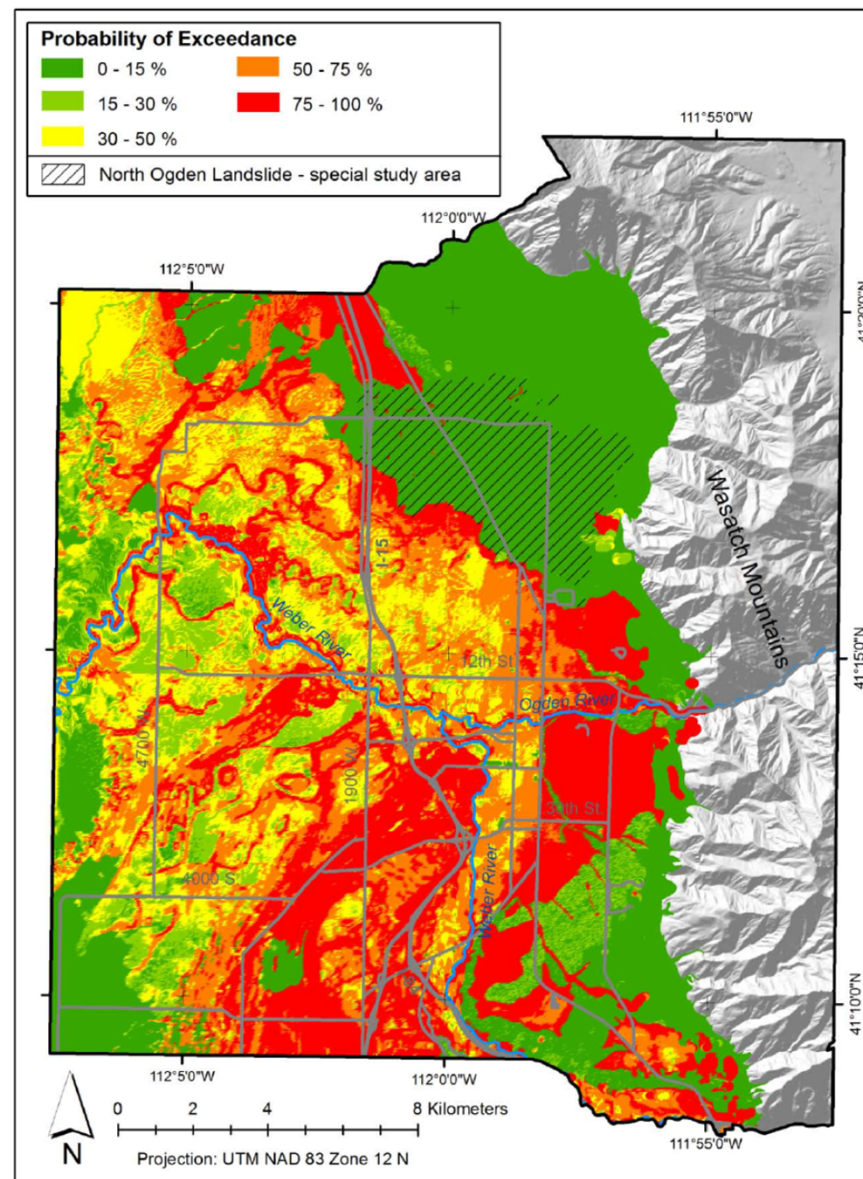


Figure 5.7. 84th percentile probabilities of lateral spread displacement exceeding 0.1 meters given a 500-year seismic event; Weber County, Utah

Weber County Liquefaction Hazard Mapping

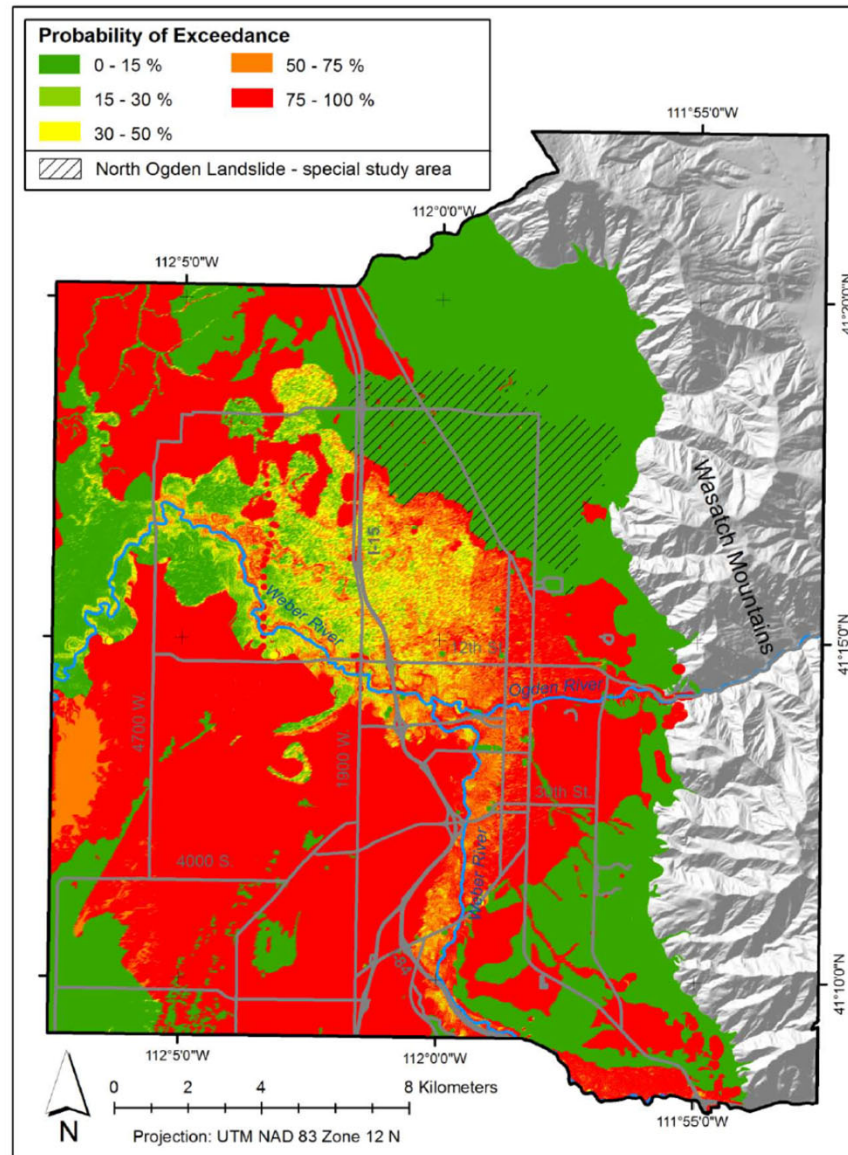


Figure 5.10. 50th percentile probabilities of lateral spread displacement exceeding 0.1 meters given a 2,500-year seismic event; Weber County, Utah

Weber County Liquefaction Hazard Mapping

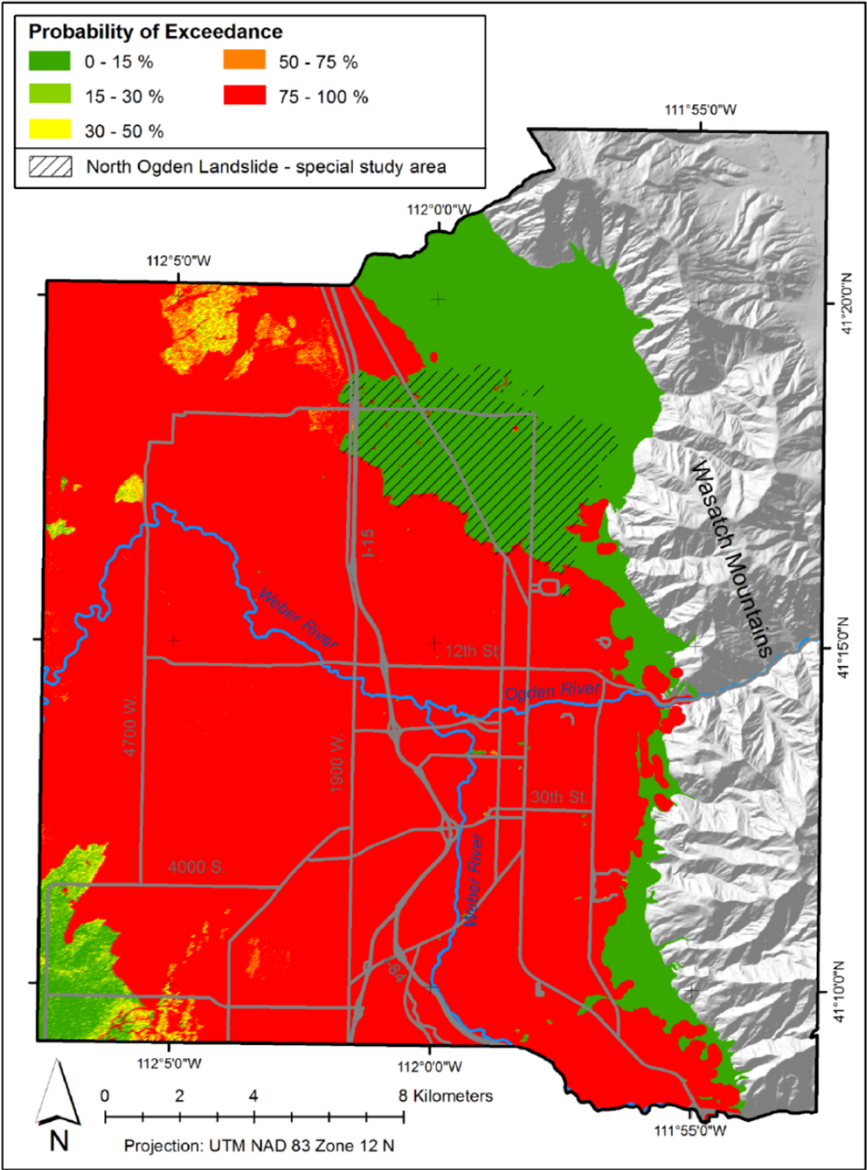


Figure 5.11. 84th percentile probabilities of lateral spread displacement exceeding 0.1 meters given a 2,500-year seismic event; Weber County, Utah

Previous Work

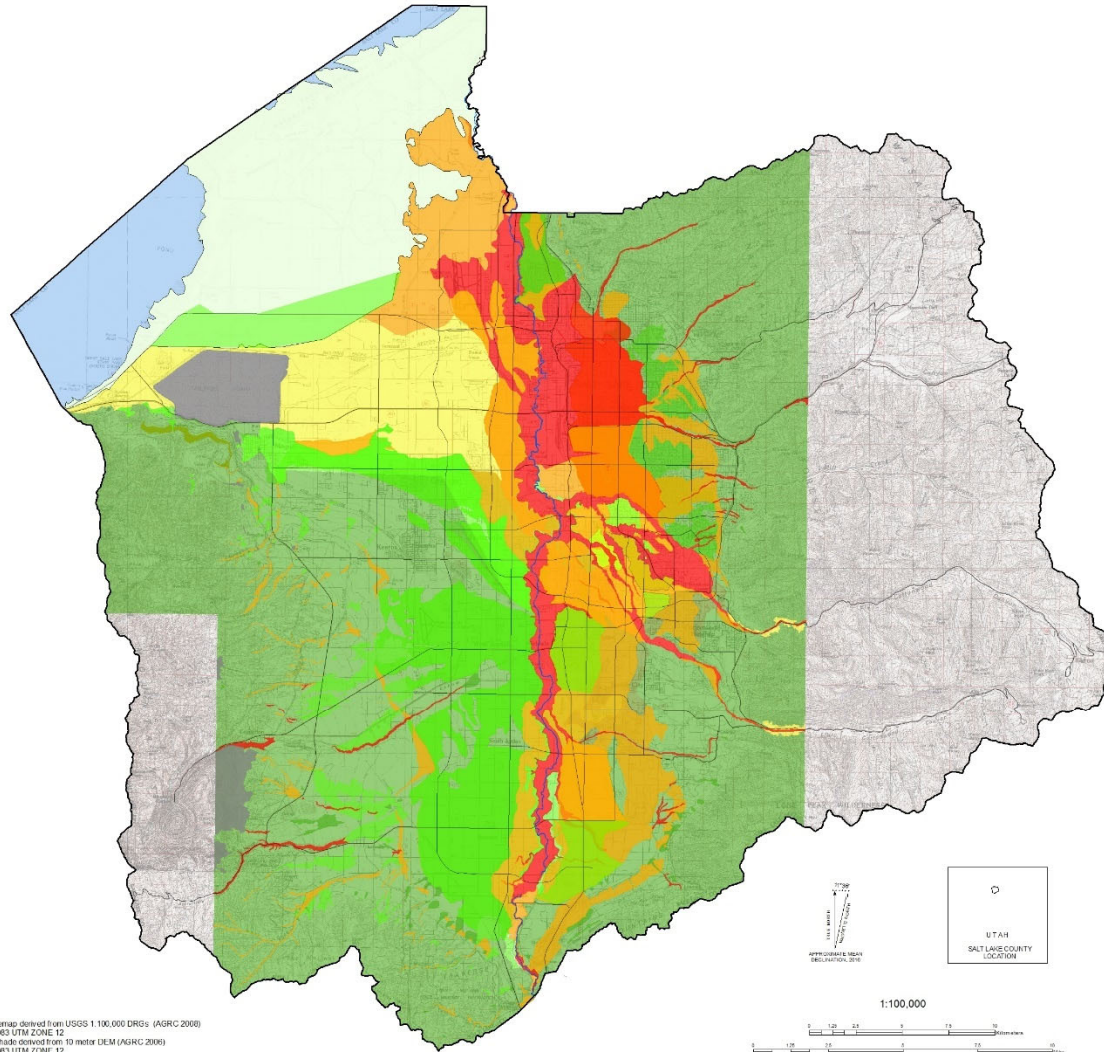
FY 2013 (FEMA – Funding for Salt Lake Co.)

FY 2014 (USGS – Funding for Mapping Utah Co.)

2013 FEMA Project U of U and UGS)

1. Develop a new model ordinance for liquefaction hazards based on input and feedback from municipalities, technical advisory groups, and others.
2. Educate various municipalities and their stake holders regarding risk-based decision making and hazard mitigation using the newly developed hazard ordinance that is coupled with the recently developed ULAG liquefaction hazard maps and support and encourage the implementation/adoption of the new liquefaction hazard ordinance in the various municipalities along the urban Wasatch Front.
3. Develop methods to apply the liquefaction hazard maps to assess post-event traffic interruptions resulting from liquefaction-induced damage
4. Educate the next generation of Utahans about earthquake hazards by focusing on a secondary education outreach curriculum and program delivered to Salt Lake and Weber Counties.

Lateral Spread Displacement Map Salt Lake Co. (85th Percentile Maps)



LATERAL SPREAD DISPLACEMENT MAP
2% PROBABILITY OF EXCEEDANCE IN 50 YEARS EARTHQUAKE
SALT LAKE COUNTY, UTAH

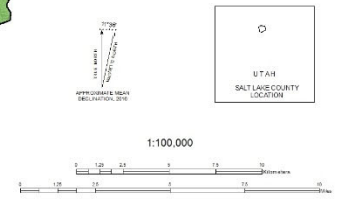
By
Department of Civil and Environmental Engineering
University of Utah
2016

EXPLANATION

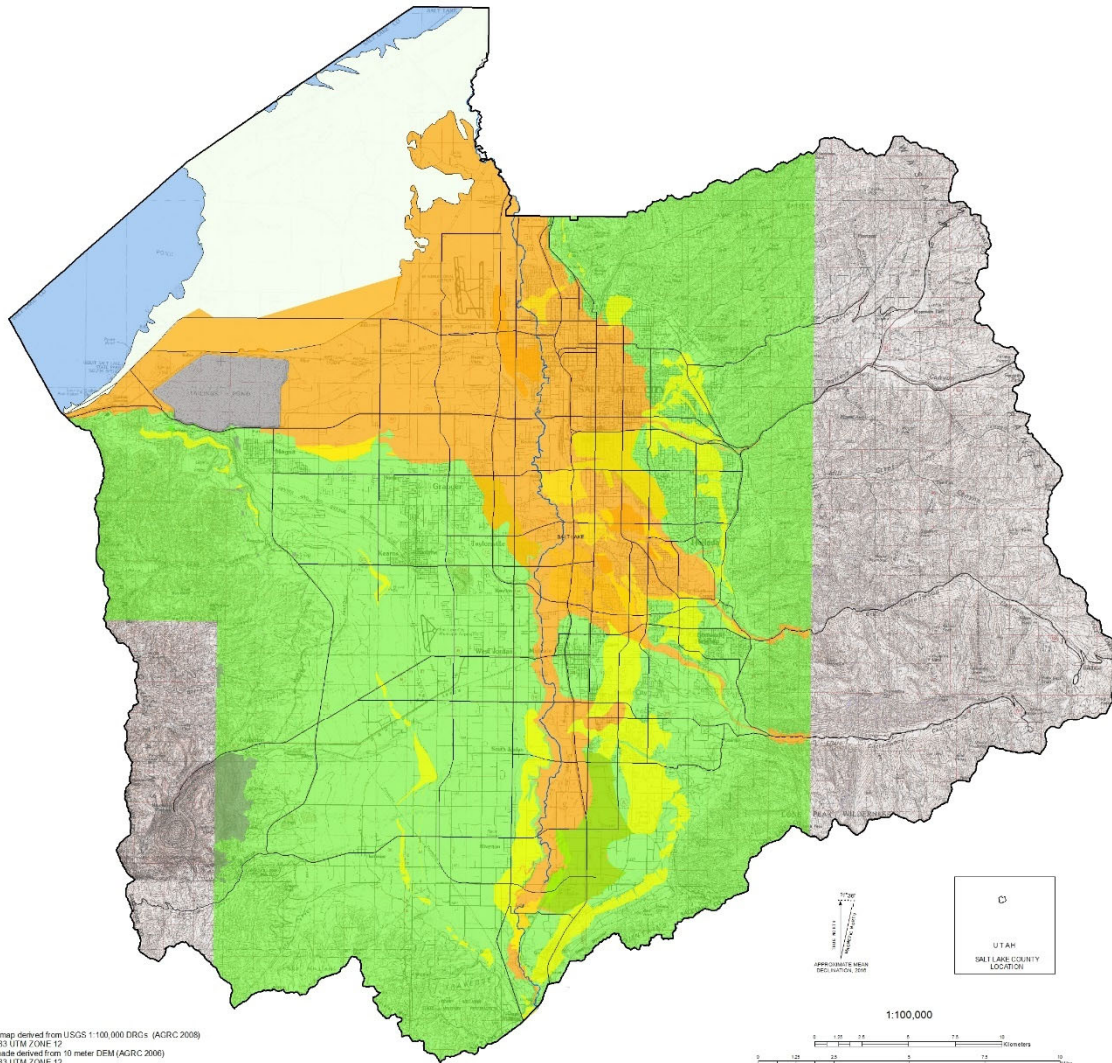
- Not Mapped - Rock or insufficient geotechnical data
- Very High - Horizontal displacement greater than 1 meter
- Moderate - Horizontal displacement between 0.1 and 0.3 m
- High - Horizontal displacement between 0.3 and 1 m
- Low - Horizontal displacement less than 0.1 m
- None - non liquifiable soil or rock
- Special Study Area
- Water

This map shows the range of horizontal displacement resulting from liquefaction-induced lateral spread for a M7.0 scenario event on the Salt Lake City segment of the Wasatch fault. The mapped estimates have an 85 percent probability of non-exceedance for the scenario event. The map is designed for use in general planning to indicate the potential need for site-specific hazard investigations. Such investigations are required to produce more detailed information. For more information regarding the use of this map, refer to the accompanying report. This map is based on limited geological, geotechnical, and hydrological data. The boundaries between displacement estimates are approximate and subject to change with additional information. The lateral spread hazard at any particular site may be different than shown because of geologic and hydrologic variations within a mapped unit, gradational and approximate map unit boundaries, and the generalized map scale. Small, localized areas of higher or lower displacement potential may exist anywhere within the mapped area, but their identification is precluded due to limitations of either data or map scale. Seasonal and long-term fluctuations in groundwater levels can alter the liquefaction potential at any given location.

Basemap derived from USGS 1:100,000 DRGs (AGRC 2006)
NAD83 UTM ZONE 12
Elevation derived from 10 meter DEM (AGRC 2006)
NAD83 UTM ZONE 12



Ground Settlement Map Salt Lake Co. (85th Percentile Maps)



**LATERAL SPREAD DISPLACEMENT MAP
2% PROBABILITY OF EXCEEDANCE IN 50 YEARS EARTHQUAKE
SALT LAKE COUNTY, UTAH**

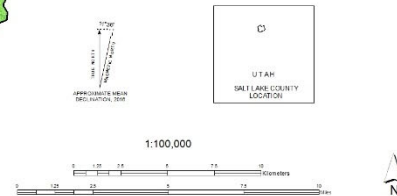
by
Department of Civil and Environmental Engineering
University of Utah
2016

EXPLANATION

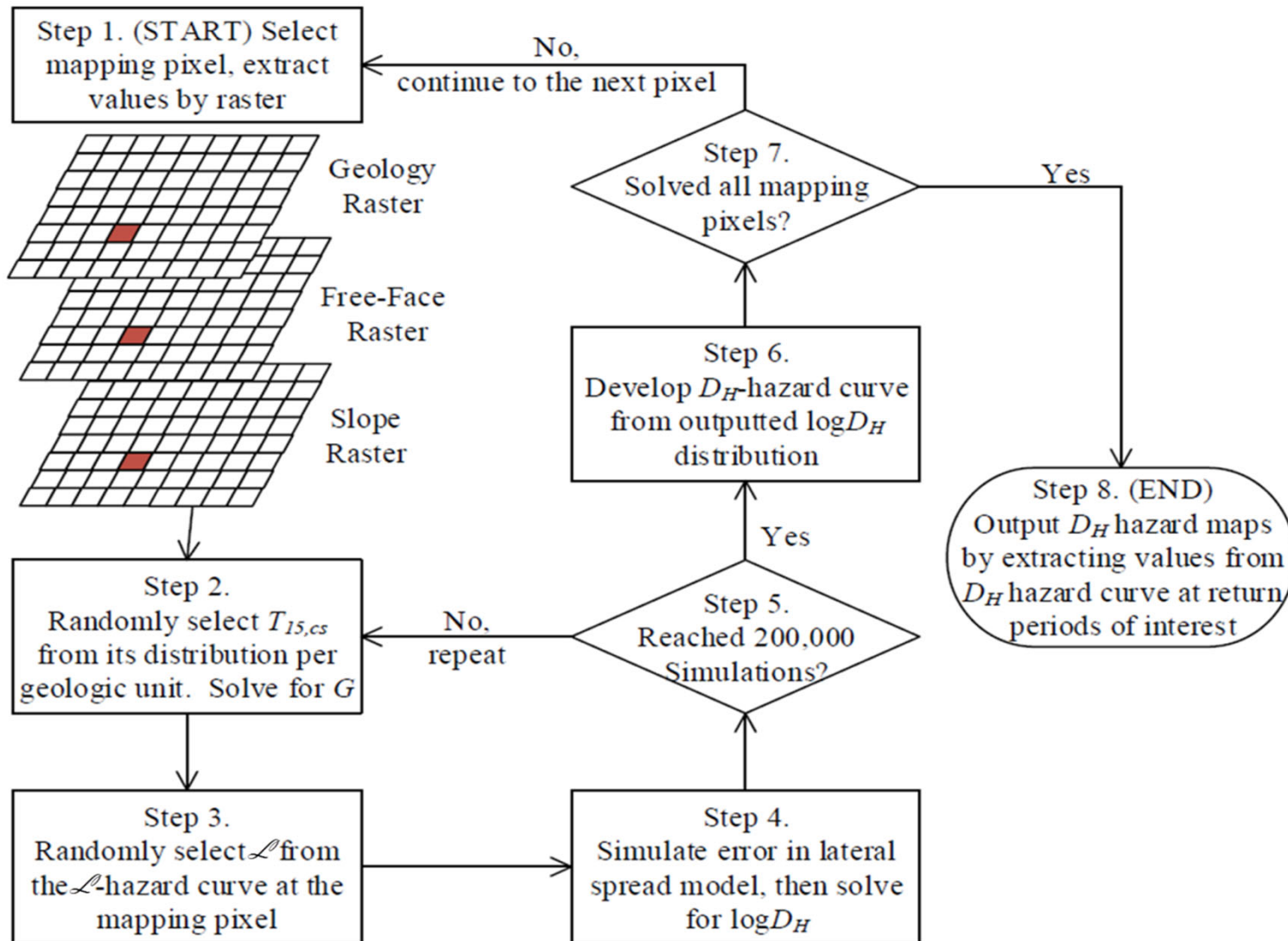
- High- Vertical displacement between 0.3-1 m
- Moderate-Vertical displacement between 0.1 and 0.3 m
- None- non liquefiable soil or rock
- Not Mapped- Rock or insufficient geotechnical data
- Special Study Area
- Water

This map shows the range of median estimates of vertical displacement (i.e., settlement) resulting from liquefaction-induced ground failure for Salt Lake County, Utah due to a seismic event associated with a M7.0 scenario event. The map is designed for use in general planning to indicate the potential need for site-specific hazard investigations. Such investigations are required to produce more detailed information. For more information regarding the use of this map, refer to the accompanying report. This map is based on limited geological, geotechnical, and hydrological data. The boundaries between displacement estimates are approximate and subject to change with additional information. The ground settlement hazard at any particular site may be different than shown because of geologic and hydrologic variations within a mapped unit, gradational and approximate map unit boundaries, and the generalized map scale. Small, localized areas of higher or lower displacement potential may exist anywhere within the mapped area, but their identification is precluded due to limitations of either data or map scale. Seasonal and long-term fluctuations in groundwater levels can alter the liquefaction potential at any given location.

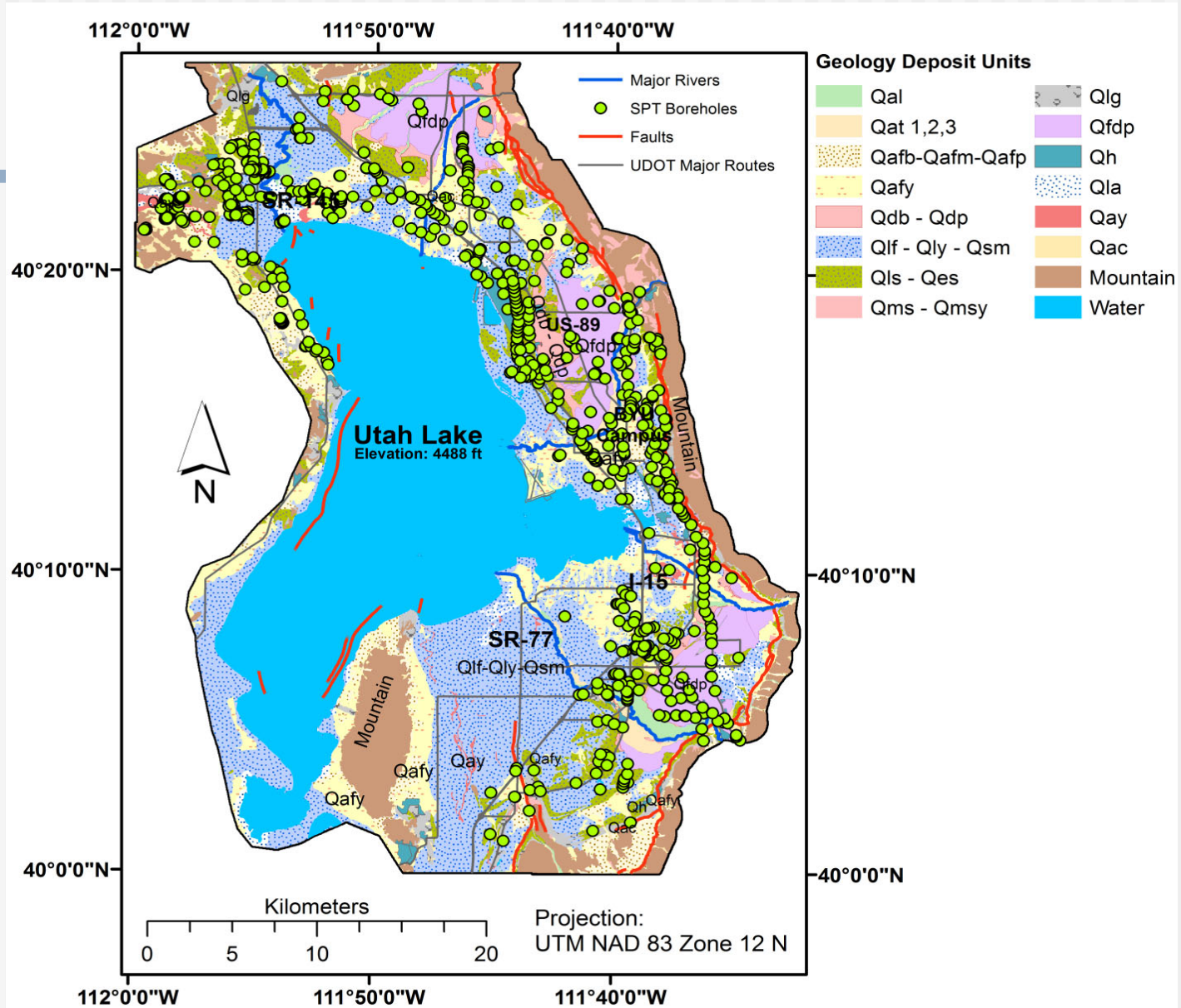
Basemap derived from USGS 1:100,000 DRGs (AGRC 2008)
NADES UTM_ZONE 12
Meters derived from 10 meter DEM (AGRC 2008)
NADES UTM_ZONE 12



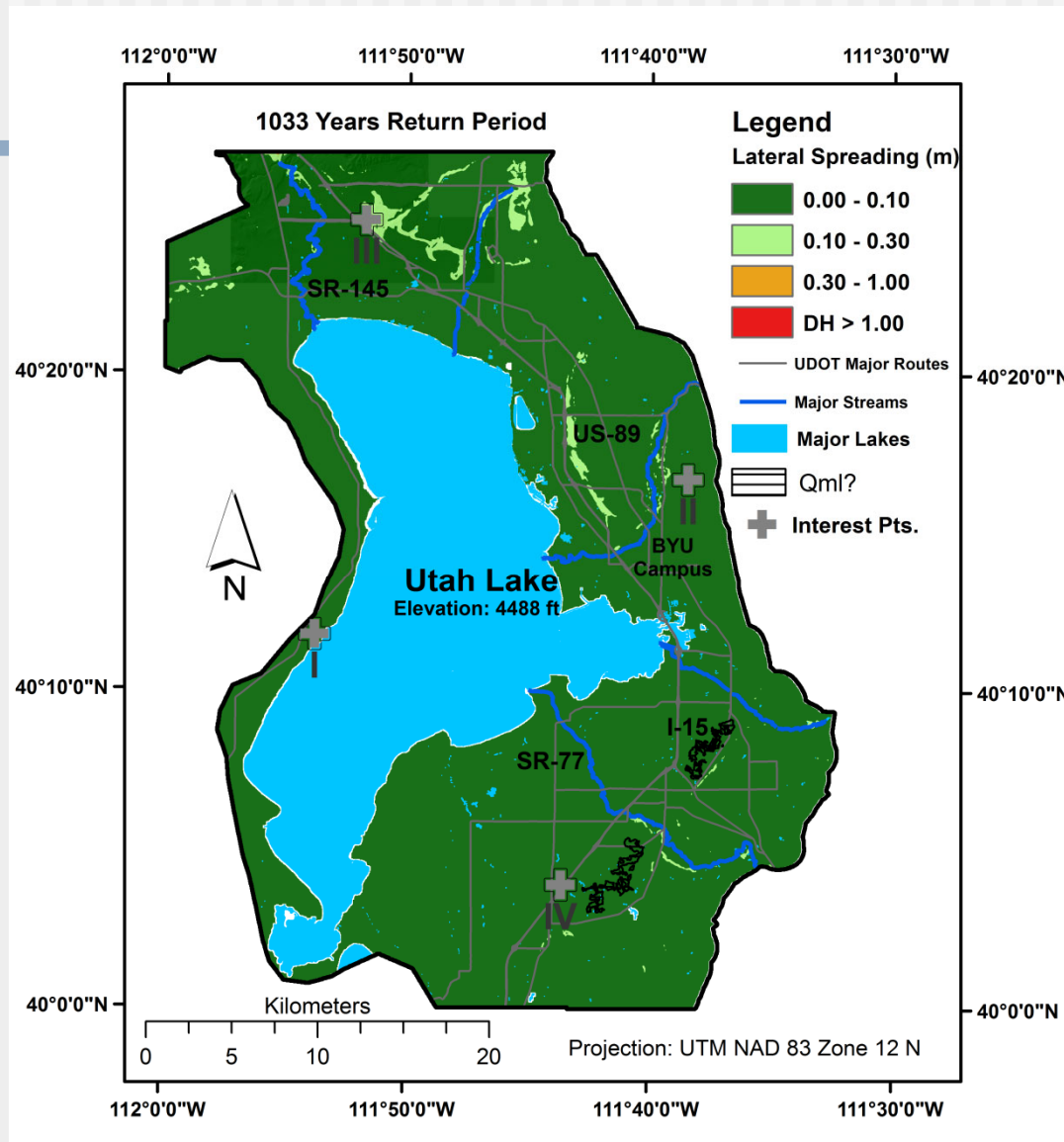
Utah Co Mapping Procedure



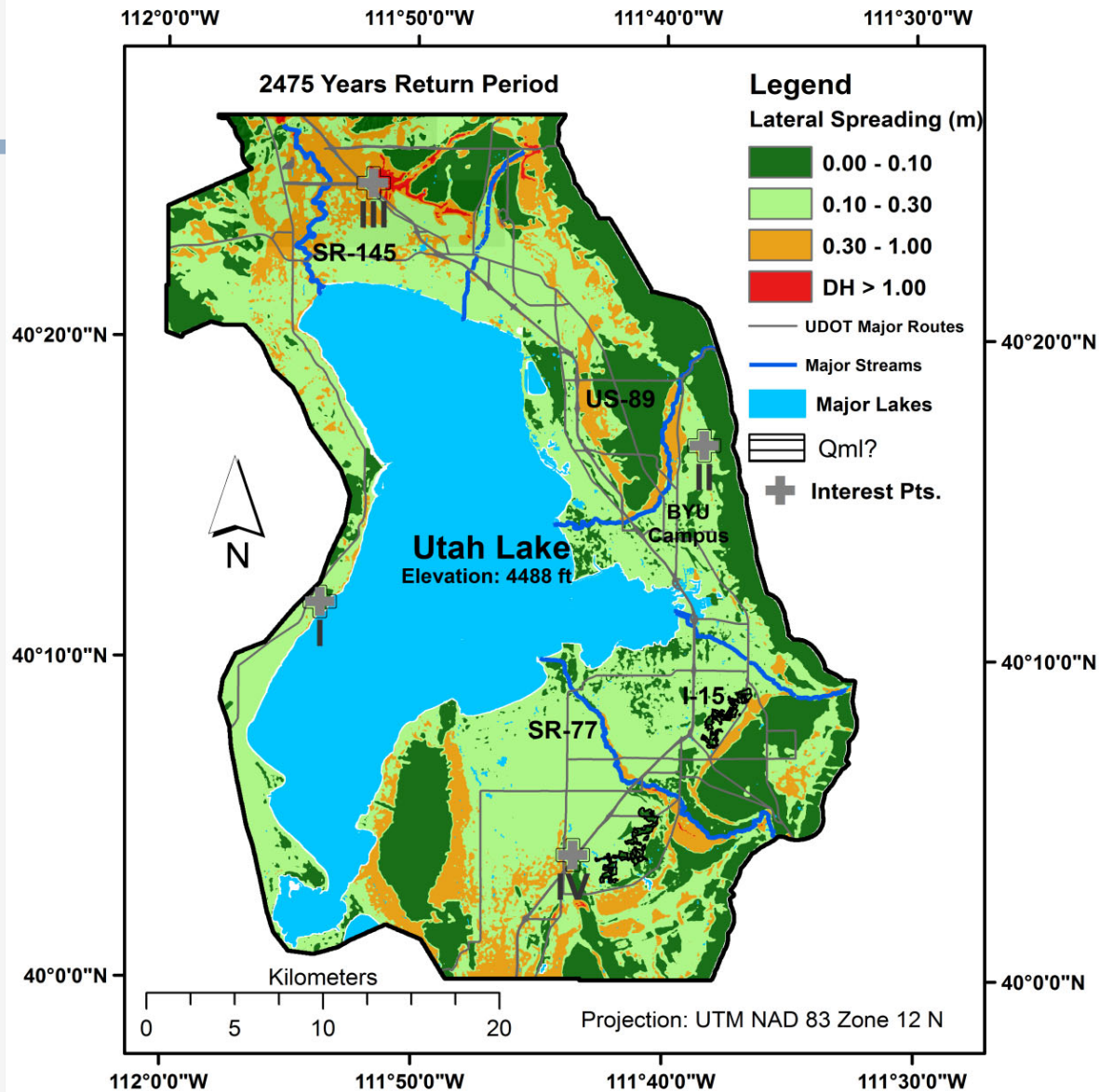
Utah Co Mapping Procedure



Utah Co Mapping Procedure



Utah Co Mapping Procedure



Current Work

FY 2017 (USGS & UDOT – Funding for Mapping Utah Co.)

- **Subsurface Data Collection**
- **Map Davis Co using methods for Utah Co.**
- **Map Salt Lake Co. using methods from Utah Co.**
- **Map Weber Co. using methods from Utah Co.**