MAPPING OF LIQUEFACTION HAZARD FOR SALT LAKE AND WEBER COUNTIES, UTAH

by
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UGA

THE UNIVERSITY OF UTAH

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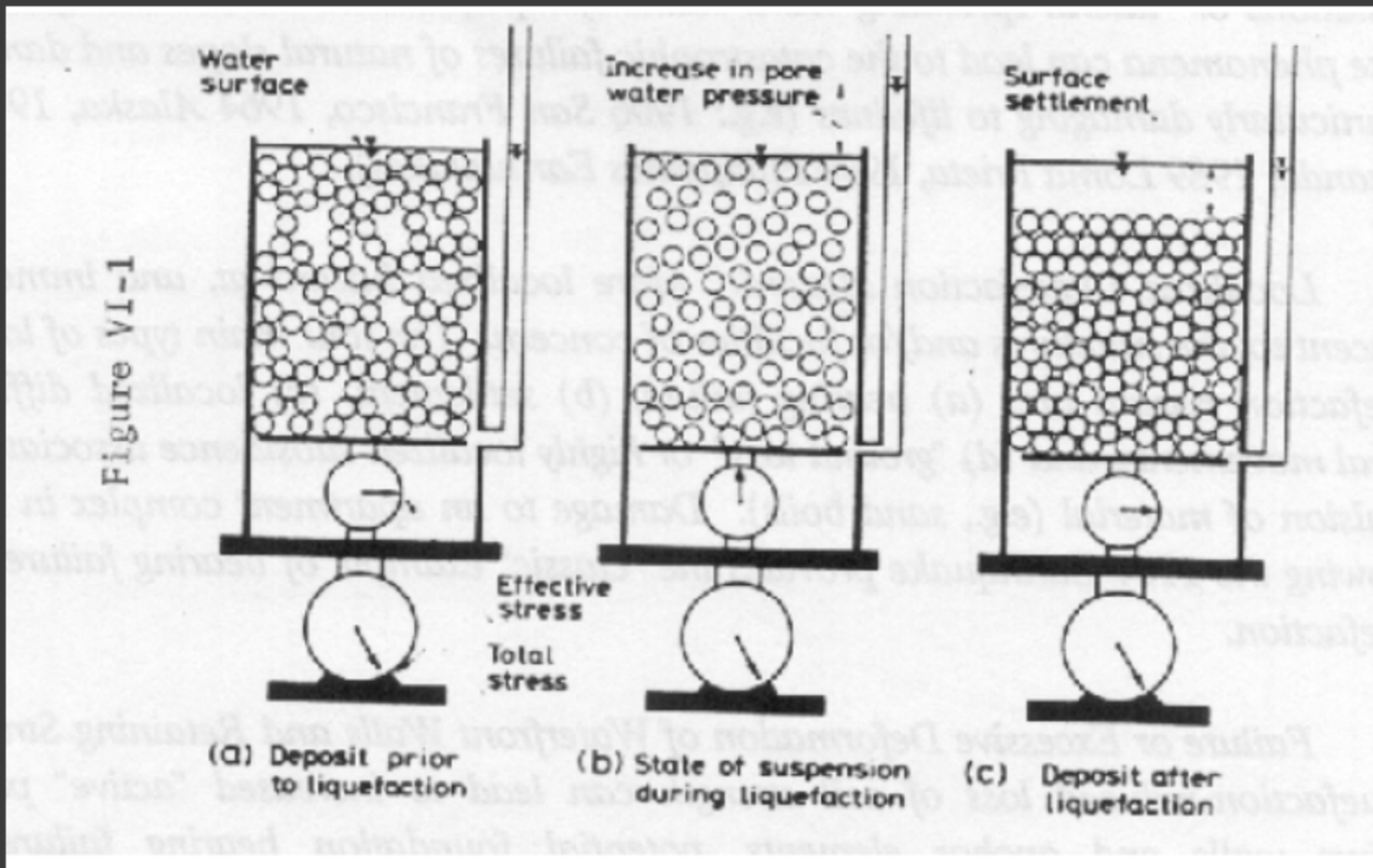
Topics

- Types of Liquefaction Damage
- Types of Liquefaction Maps
- Estimation of Liquefaction Potential
- Estimation of Ground Displacement
- Estimation of Settlement
- Other Mapping Inputs
- Map Creation
- Map Examples

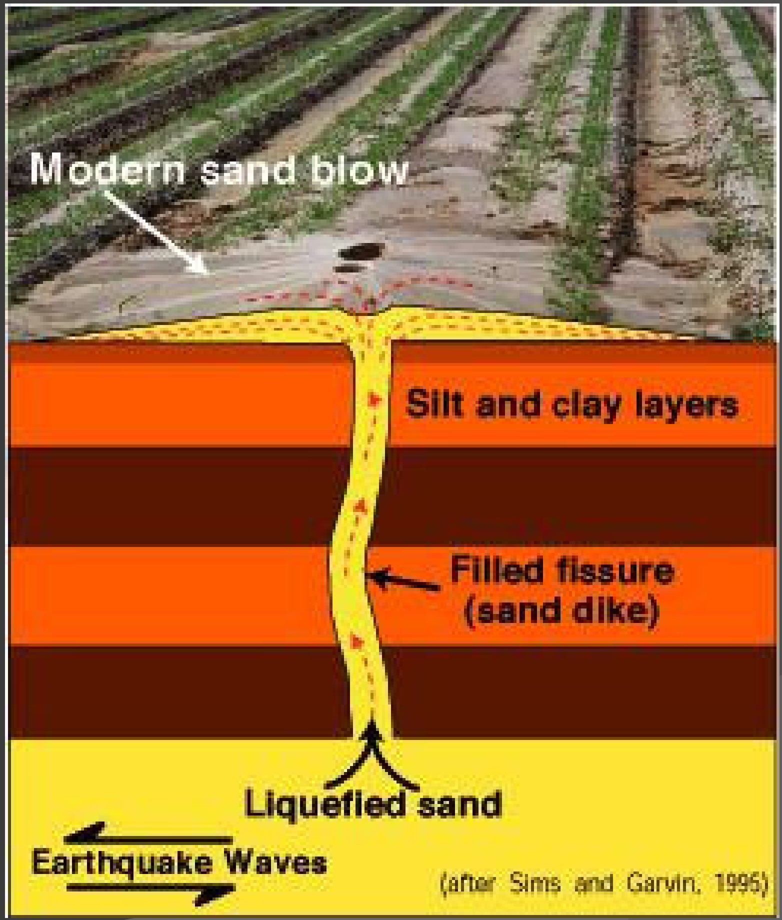
Types of Liquefaction Damage



What is liquefaction?

Types of Liquefaction Damage

Sand Blow or Sand Volcano



Types of Liquefaction Damage

Ground Oscillation

Marina District, San Francisco, 1989 Loma Prieta Earthquake

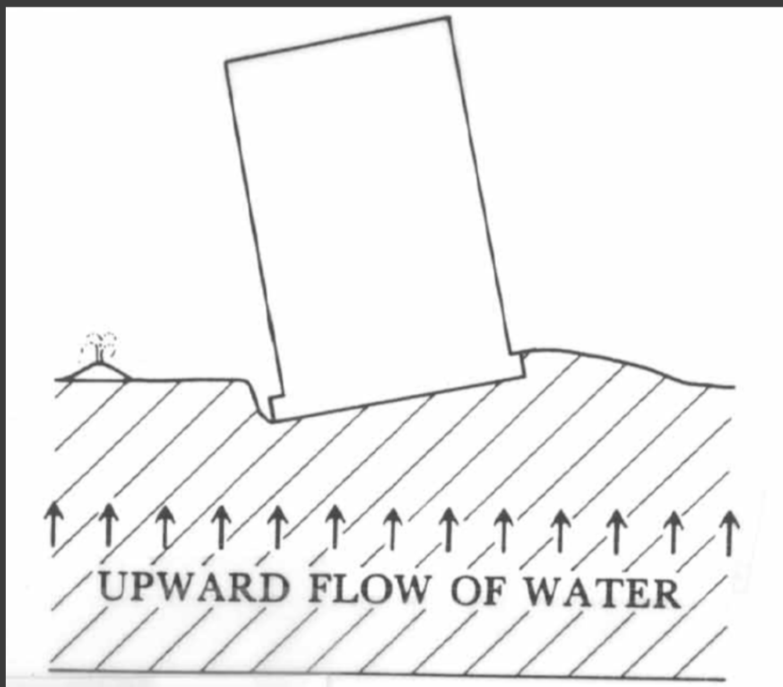
Types of Liquefaction Damage

Port of Kobe, 1995
Kobe, Japan
Earthquake

Ground Settlement

2010 Christchurch Earthquake

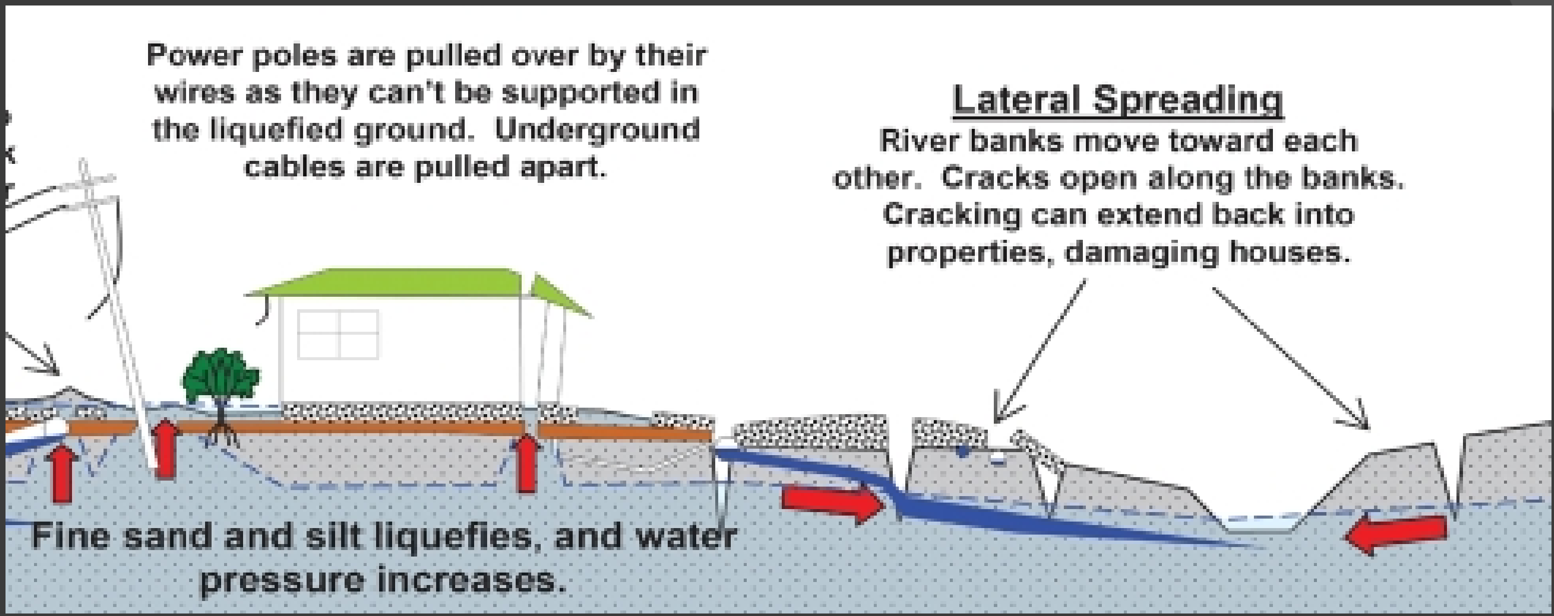
Types of Liquefaction Damage



Bearing Capacity Failure

1964 Niigata, Japan Earthquake

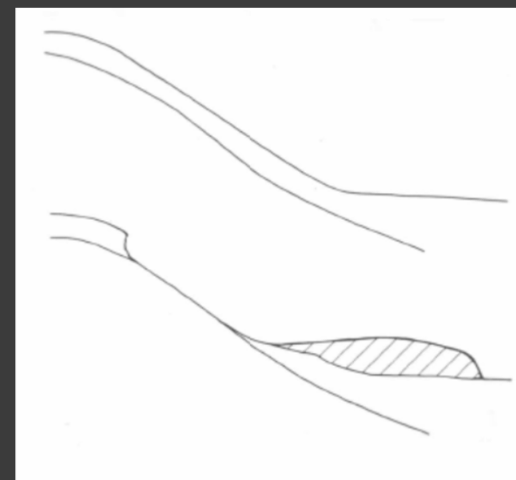
Types of Liquefaction Damage



Lateral Spread

1964 Niigata, Japan Earthquake

Types of Liquefaction Damage



Valdez, 1964 Alaska Earthquake

Flow Failure

Seward, 1964 Alaska Earthquake

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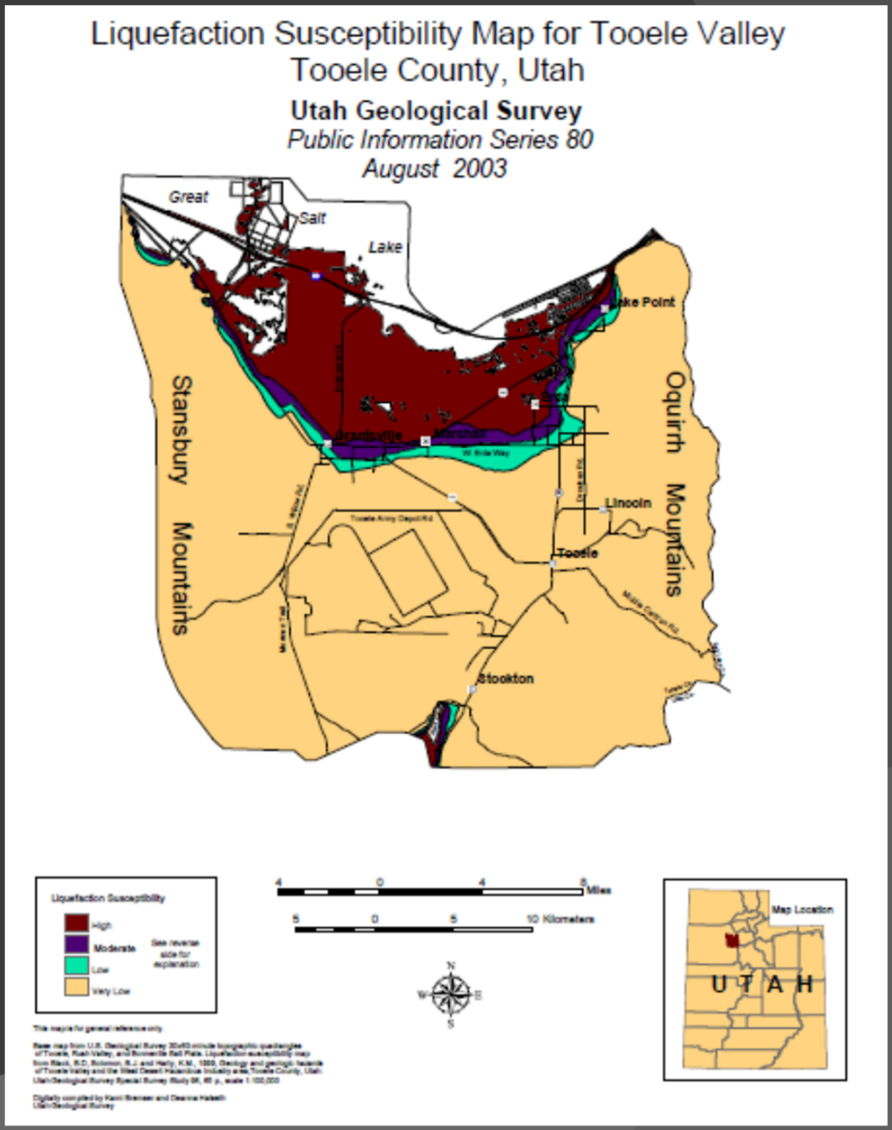
- Example Maps

Types of Liquefaction Maps

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

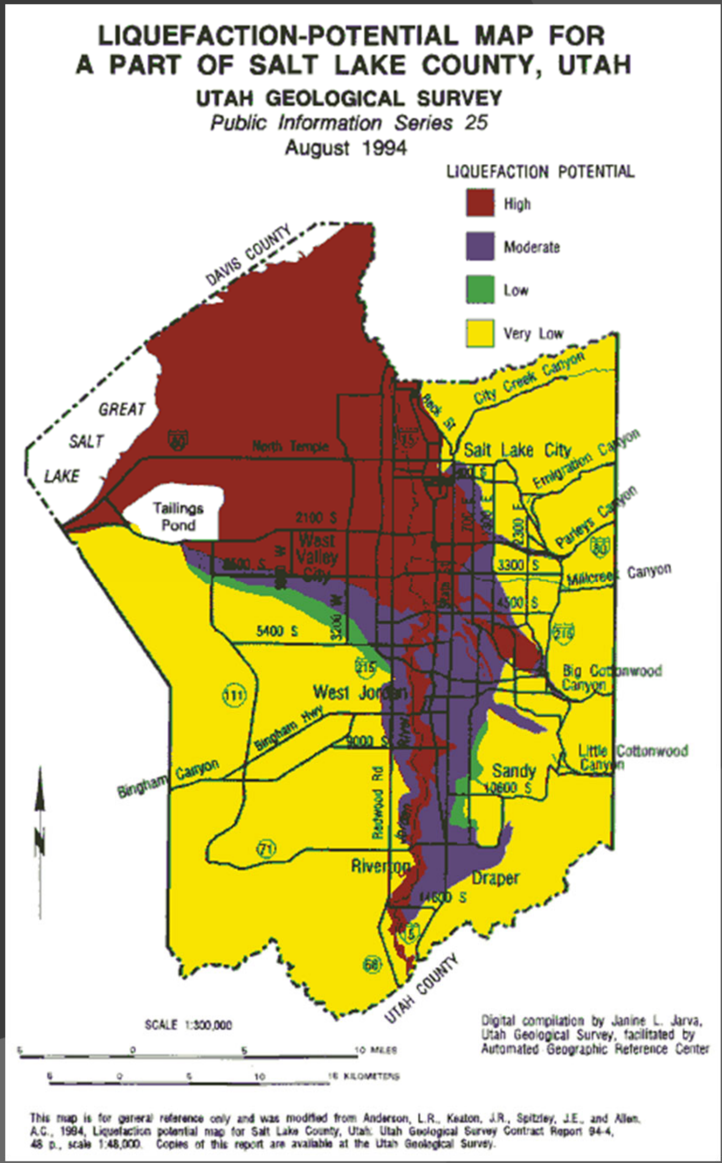
Types of Liquefaction Maps

- Liquefaction Susceptibility Maps
  - Show liquefaction hazard based on susceptibility (capacity), but do not consider demand (size of amplitude of strong ground motion)



Types of Liquefaction Maps

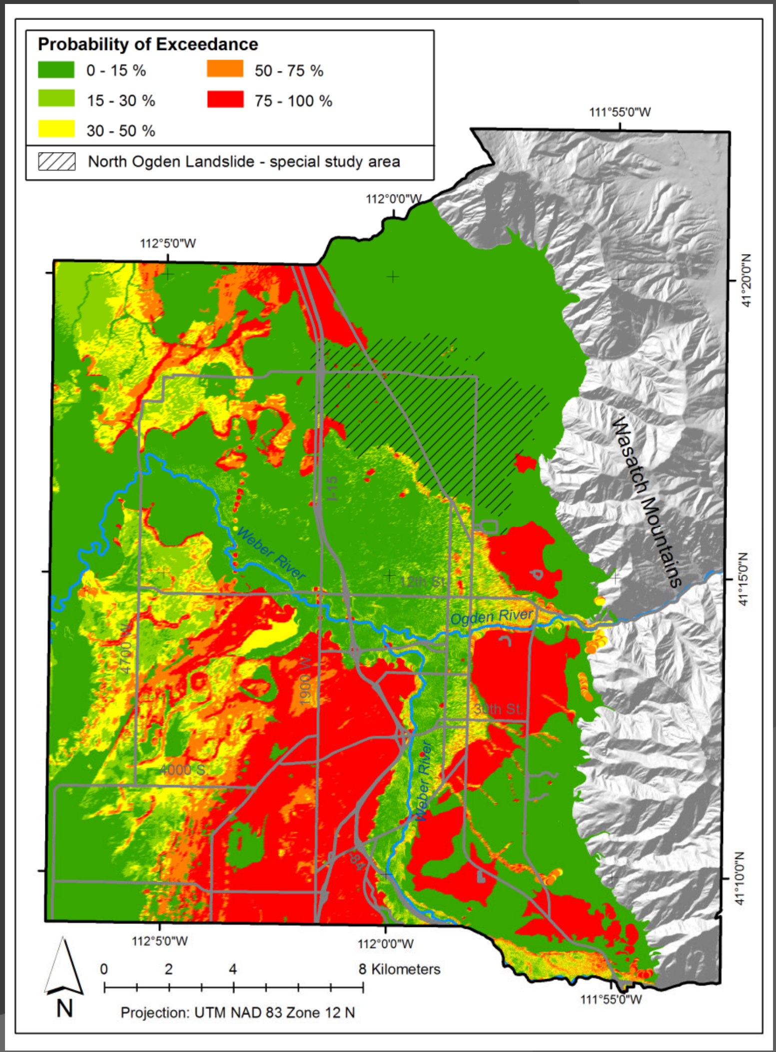
- Liquefaction Potential Maps
  - Combine liquefaction susceptibility (capacity) with seismic input (demand).
  - Demand can be expressed as a deterministic scenario event or a probabilistic-based estimate obtained from the national seismic hazard maps



Liquefaction potential for approximate 0.2g pga (Anderson and Keaton)

Types of Liquefaction Maps

- Ground Failure Maps
  - Consider liquefaction potential
  - Consider consequences of liquefaction (i.e., displacement)



- Median probabilities of lateral spread displacement exceeding lateral spread 0.3 m, 2,500-year return period seismic event

Types of Liquefaction Maps (ULAG Maps funded by NEHRP)

- Liquefaction Potential and Ground Displacement Maps
- Seismic Strong Motion (SM) Inputs for Liquefaction Potential Maps
  - M7.0 Earthquake
  - SM with 10% probability of exceedance in 50 years
  - SM with 2% probability of exceedance in 50 years
  - Fully aggregated PSHA input
- Lateral Spread maps (using above scenarios)
- Ground settlement maps (using above scenarios)

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- Map Examples

Estimation of Liquefaction Potential

$$P(L) = \sum P[L \mid A, M] \; P[A, M]$$

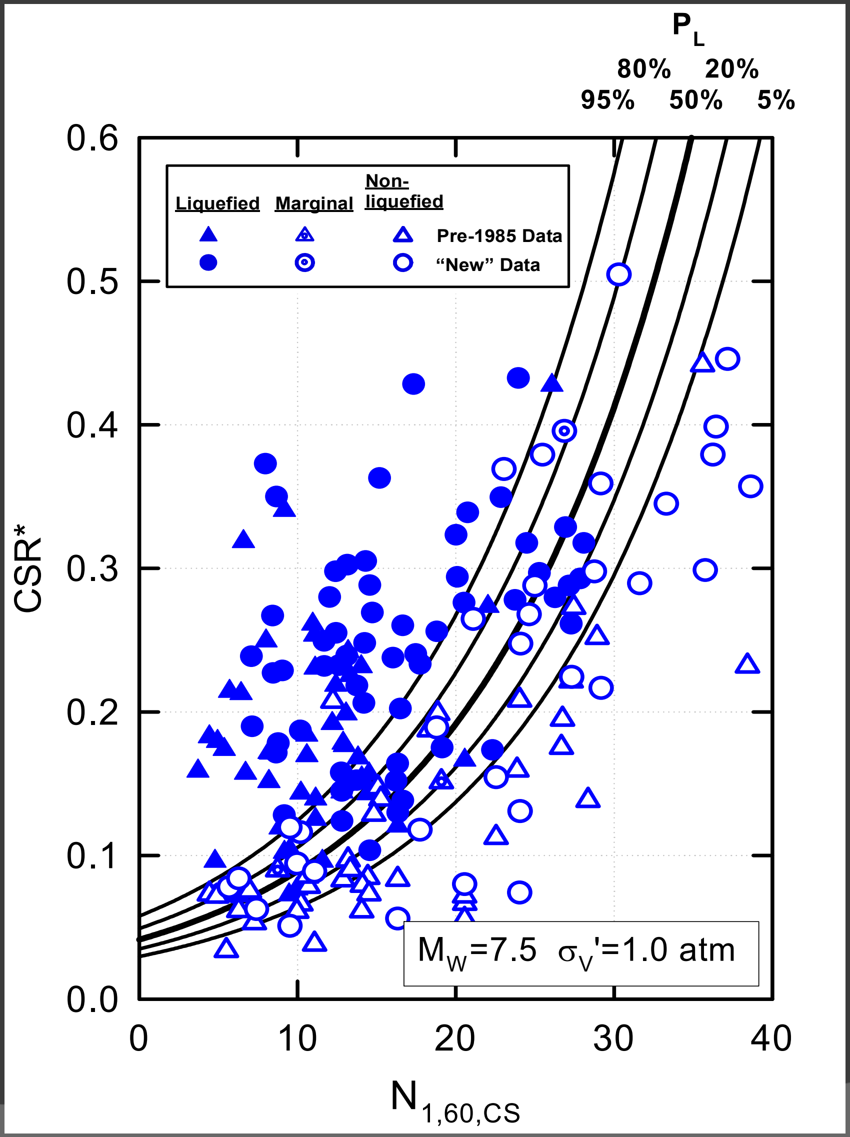
where:

P(L) = annual probability of liquefaction

P [L | A,M] = conditional probability of liquefaction given the peak ground acceleration and the earthquake magnitude,

P [A, M] = joint probability density function of peak ground acceleration and earthquake magnitude.

Estimation of Liquefaction Potential



Recommended "Probabilistic" SPT-Based Liquefaction
Triggering Correlation

(For MW=7.5 and sv'=1.0 atm)

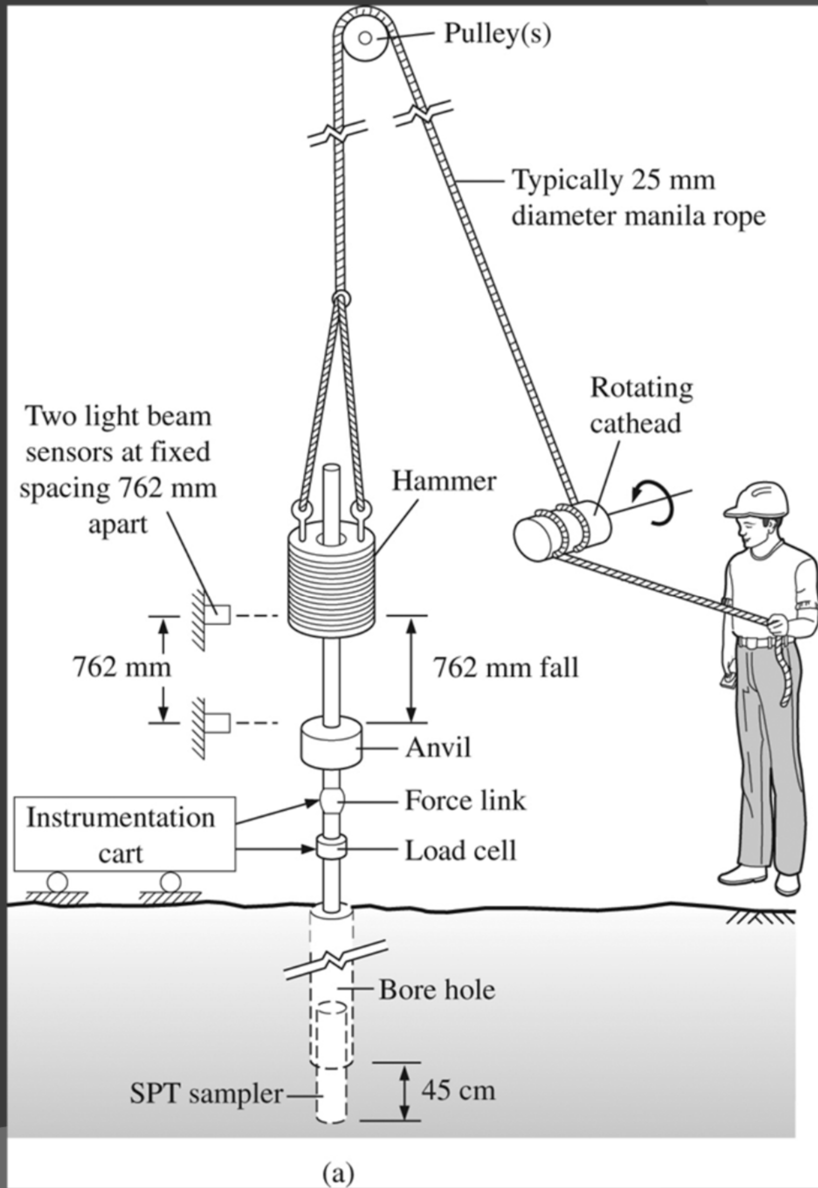
(Seed et al. 2003)

Estimation of Liquefaction Potential

- Subsurface data collection
  - Standard Penetration Testing (SPT)
  - Cone Penetrometer Testing (CPT)
  - Shear Wave Velocity Testing (VS)

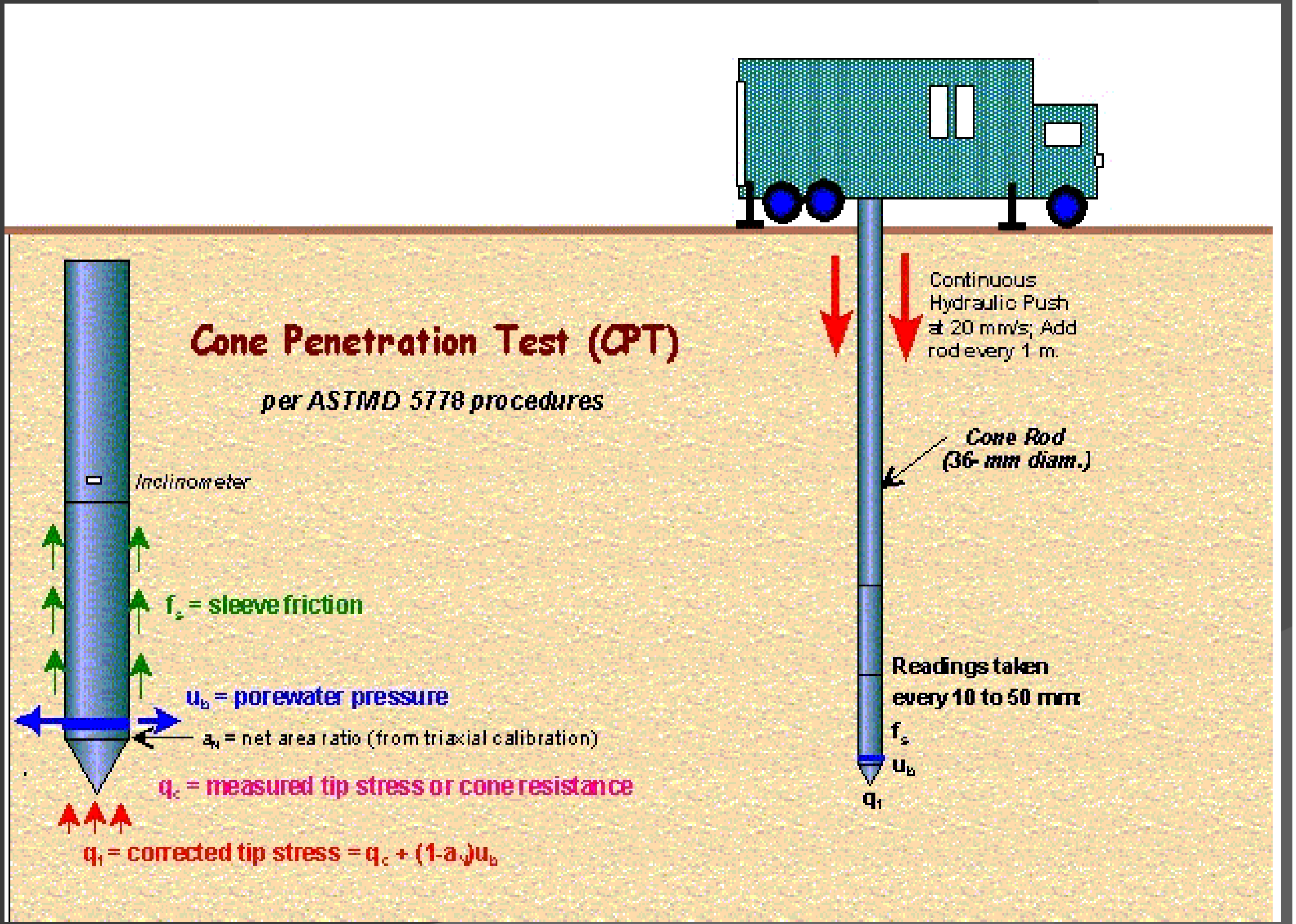
Estimation of Liquefaction Potential

- Subsurface data collection
  - Standard Penetration Testing (SPT)



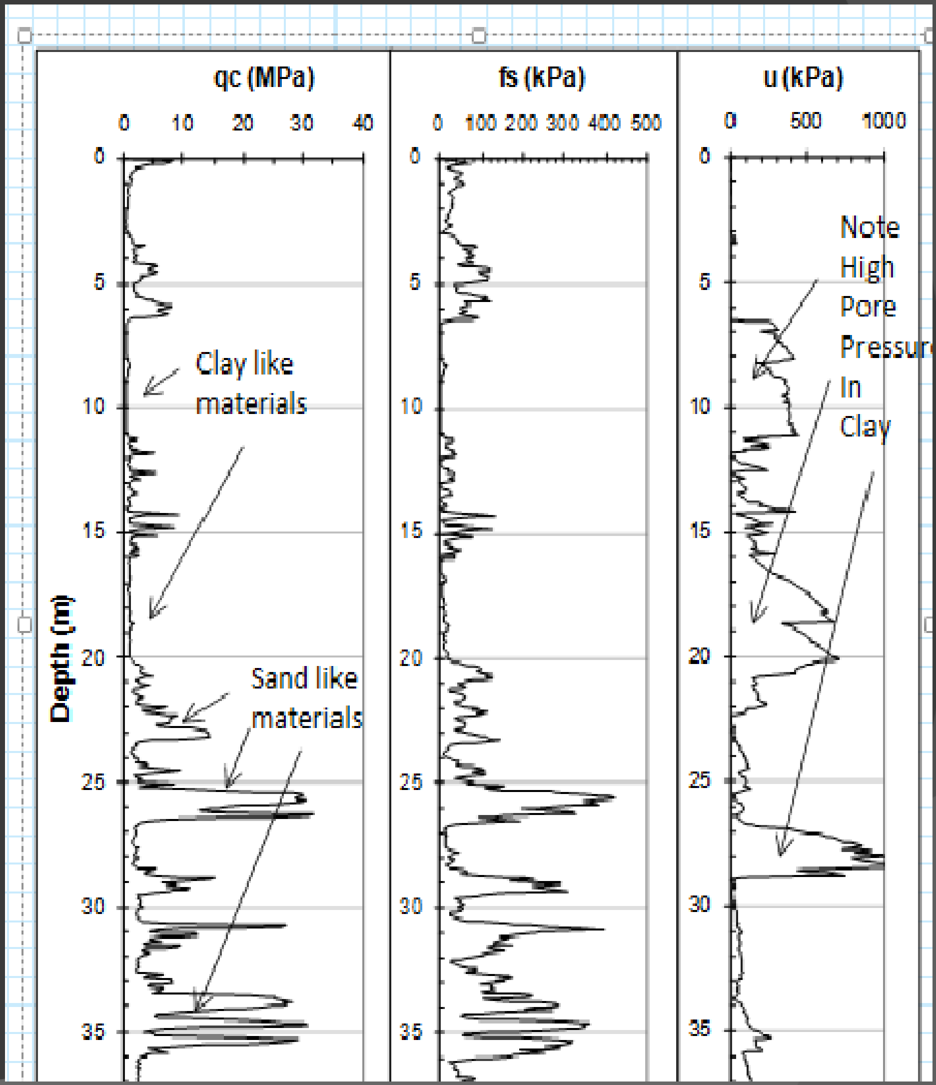
Estimation of Liquefaction Potential

- Subsurface data collection
  - Cone Penetro-meter Testing (CPT)



Estimation of Liquefaction Potential

- Subsurface data collection
  - Cone Penetrometer Testing (CPT)



Estimation of Liquefaction Potential

- Subsurface data collection
  - Shear Wave Velocity Testing (VS)
    - Downhole (SCPT)
  - Surface geophysical techniques
    - Spectral Analysis of Surface Waves (SASW)

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Estimation of Ground Displacement

- $P(DH > x) = \Sigma P[(DH > x) | L] P[L | A, M, R] P[A, M, R]$

  Where:

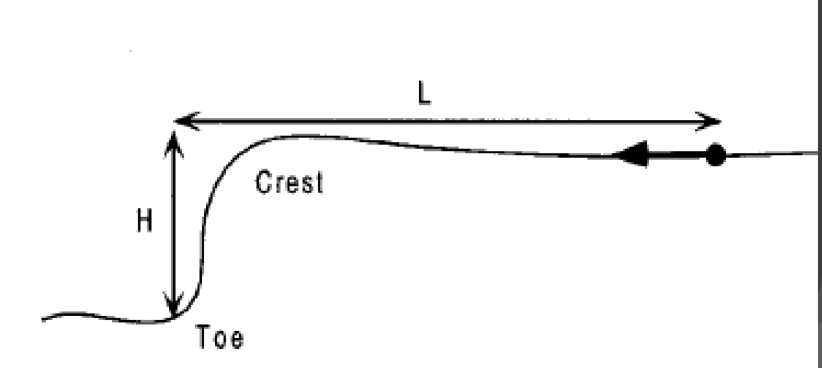
  - P(DH>x) = The probability of lateral spread exceeding a threshold value (e.g., x= 0.1 m and 0.3 m)
  - P[L| A,M,R] = the probability of liquefaction given an acceleration, magnitude, and source distance.
  - P[A,M,R] = joint probability density function of peak ground acceleration, magnitude and source distance.

Estimation of Ground Displacement

Youd, Hansen, Bartlett (2002) Empirical Model

$$LogD_H = \begin{array}{c} b_o + b_{off}\alpha + b_1 M + b_2 LogR^* + b_3 R + b_4 LogW + b_5 LogS + b_6 LogT_{15} + \\ + b_7 Log(100 - F_{15}) + b_8 Log(D50_{15} + 0.1\ \text{mm}) \end{array}$$

- Seismic Factors
  - *M*, *R*
- Topographic Factors
  - *W*, *S*
- Geotechnical Factors
  - T_{15}, F_{15}, $D50_{15}$



Free-face ratio: *W (%) = H / L * 100*

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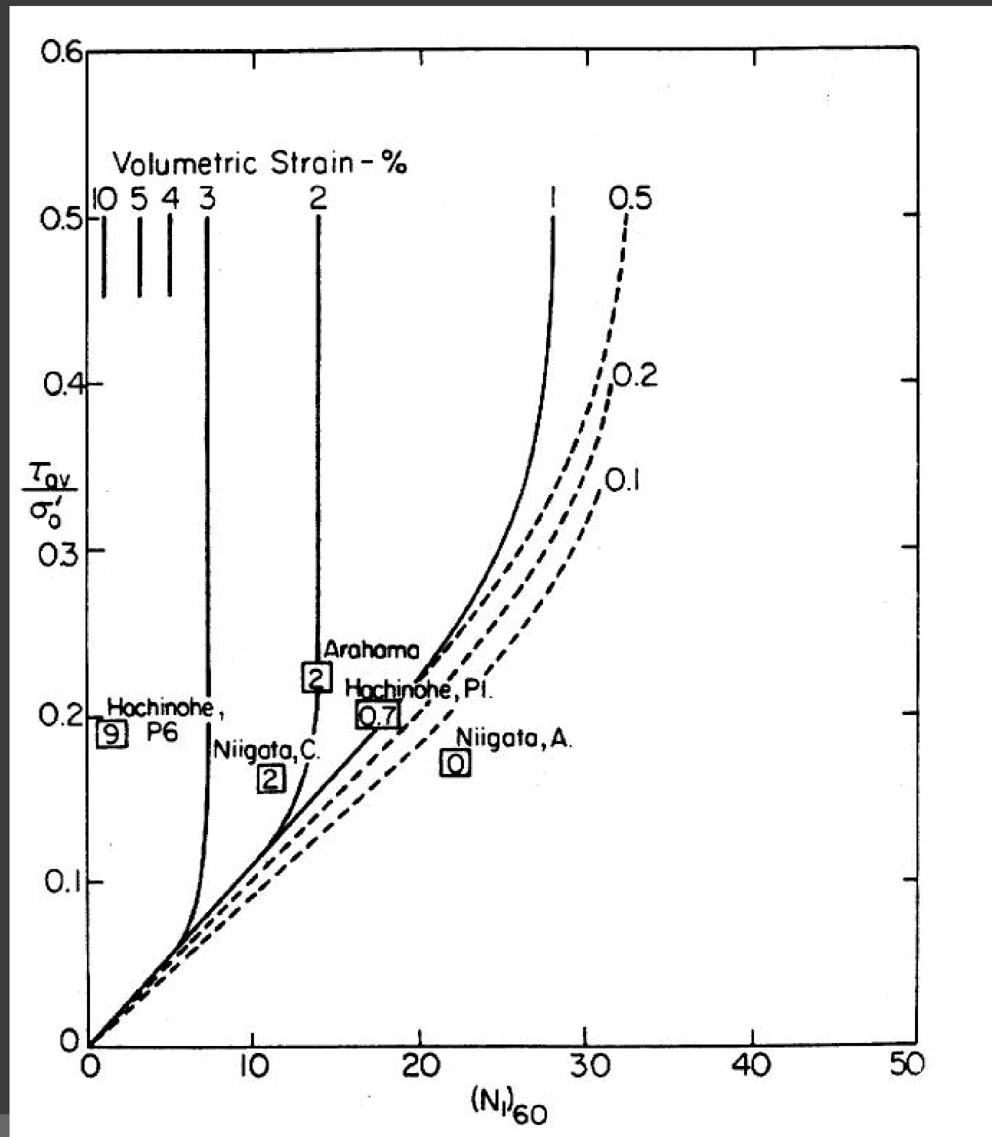
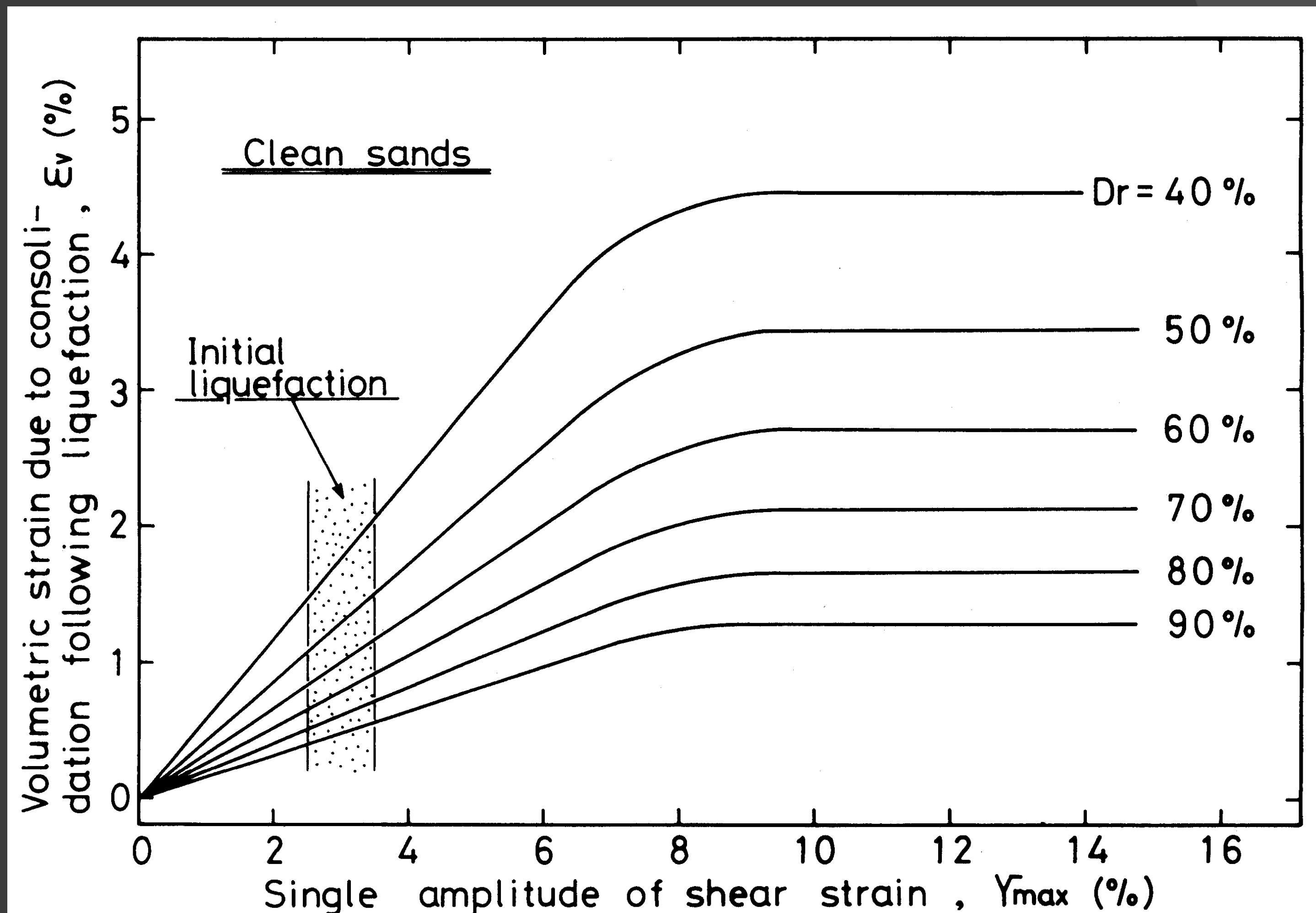
Estimation of Settlement

(Tokimatsu
And Seed, 1987)



Estimation of Settlement

(Ishihara and Yoshimine 1992).



Topics

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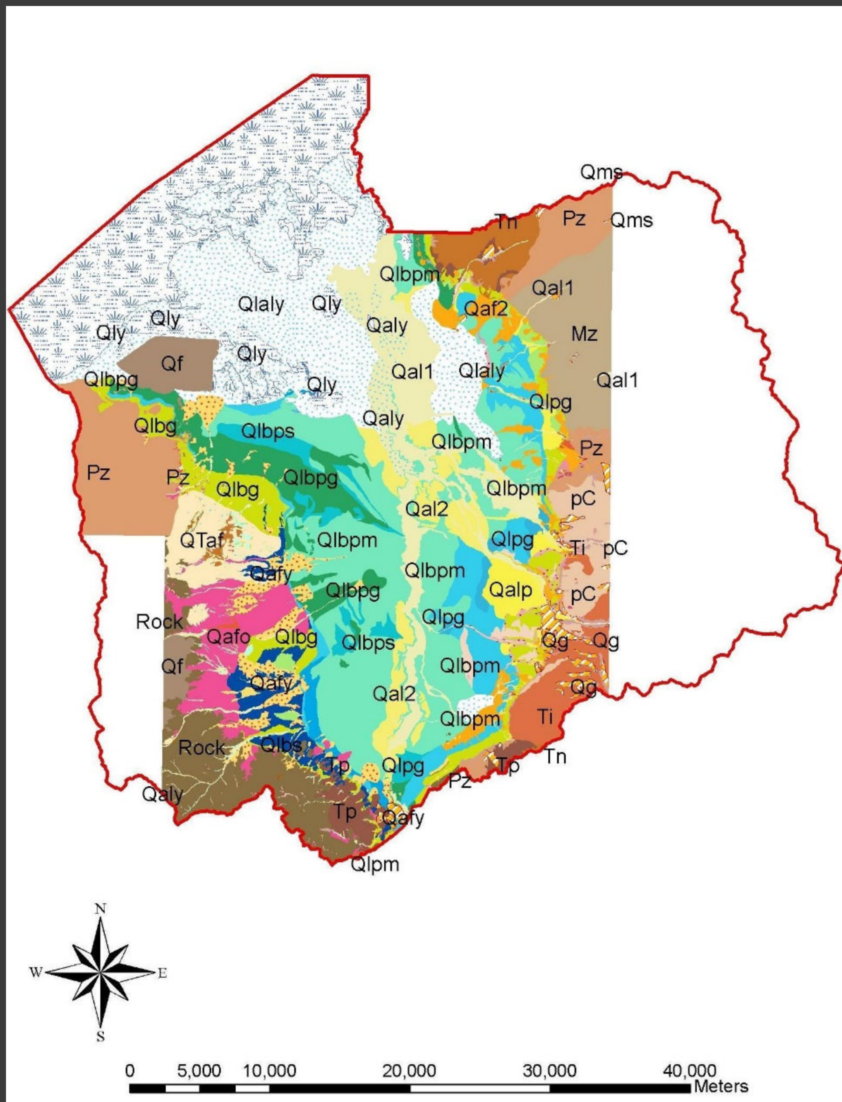
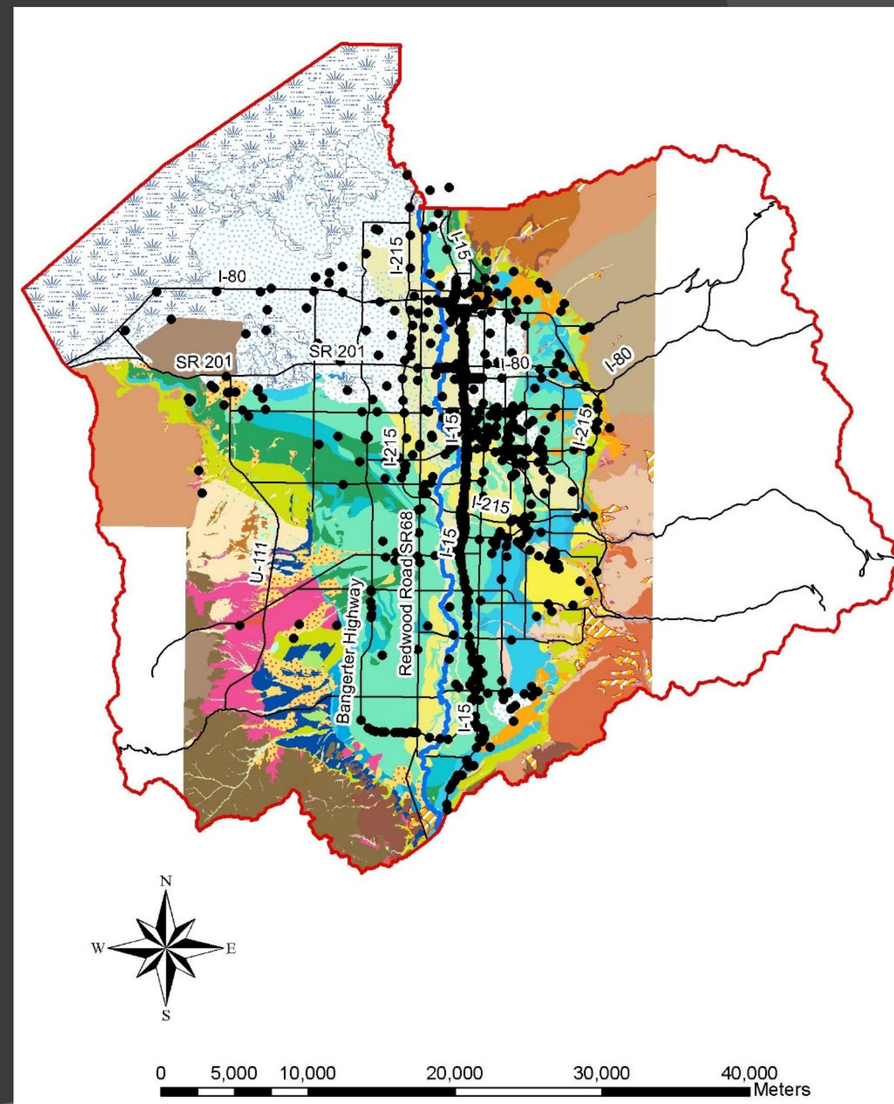
Other Mapping Inputs

- Surficial geologic maps
- Topographical maps
- Digital Elevation Model (DEM)
- Groundwater depths
- Aerial photography
- Investigation Reports
- Surficial geologic mapping (Personious and Scott, 1992, Biek et al. 2004, and Miller 1980)
- Fault location data
- River and channel locations and depths
- Great Salt Lake location
- Peak ground acceleration map (pga, Wong et al. 2002)

Other Mapping Inputs

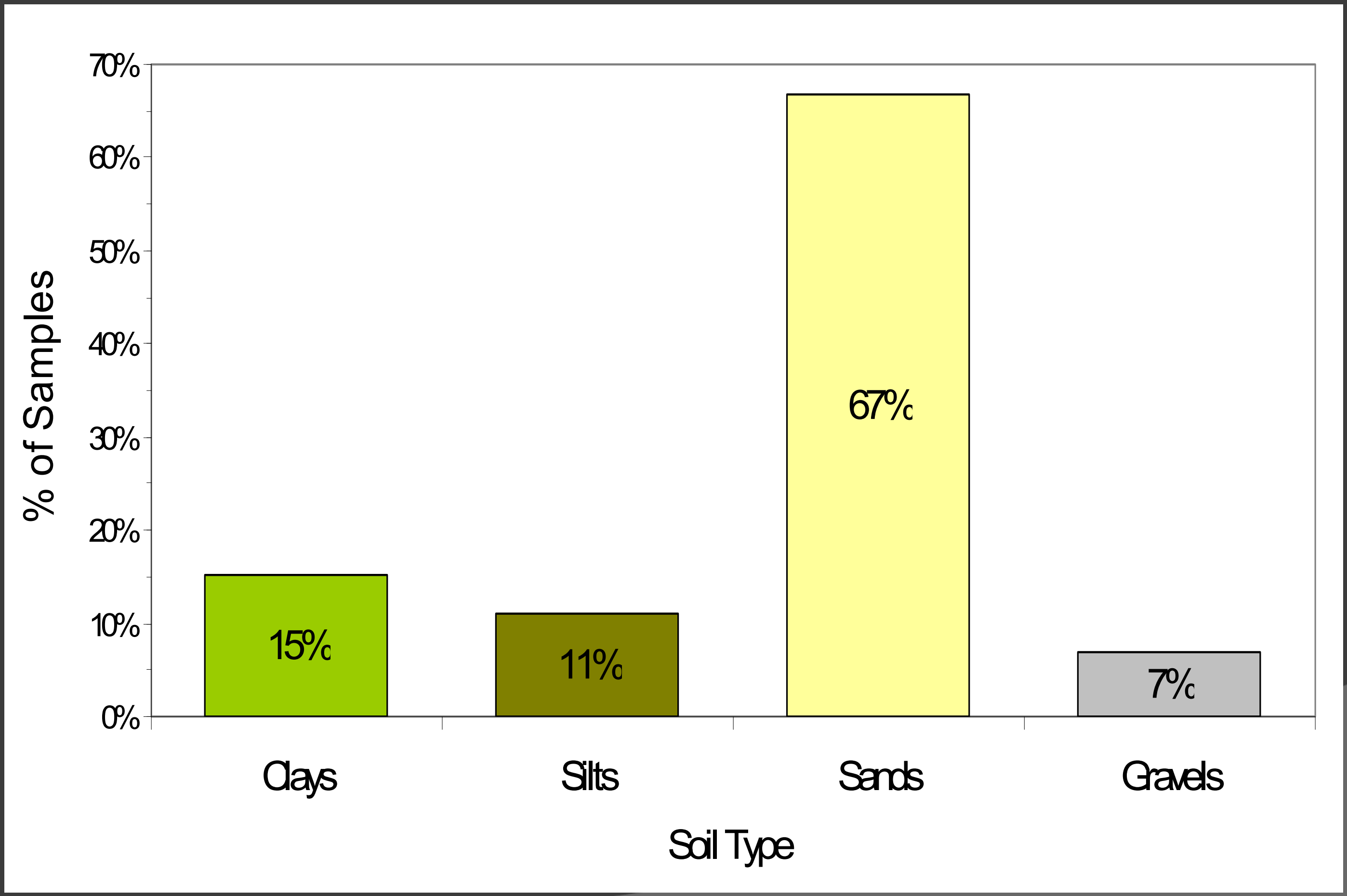




Geologic Map

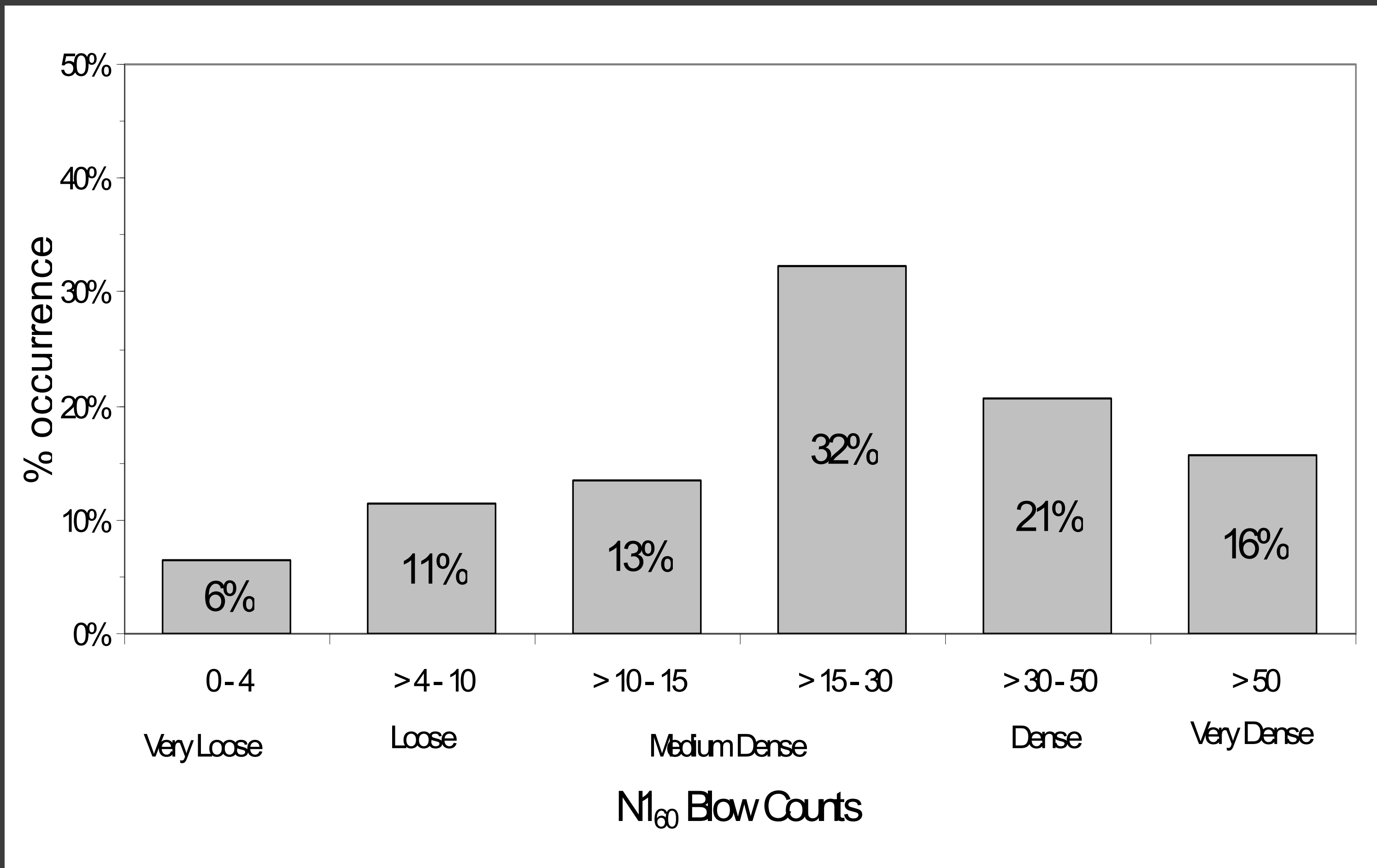
Other Mapping Inputs

Qal_1 – Stream alluvium 1



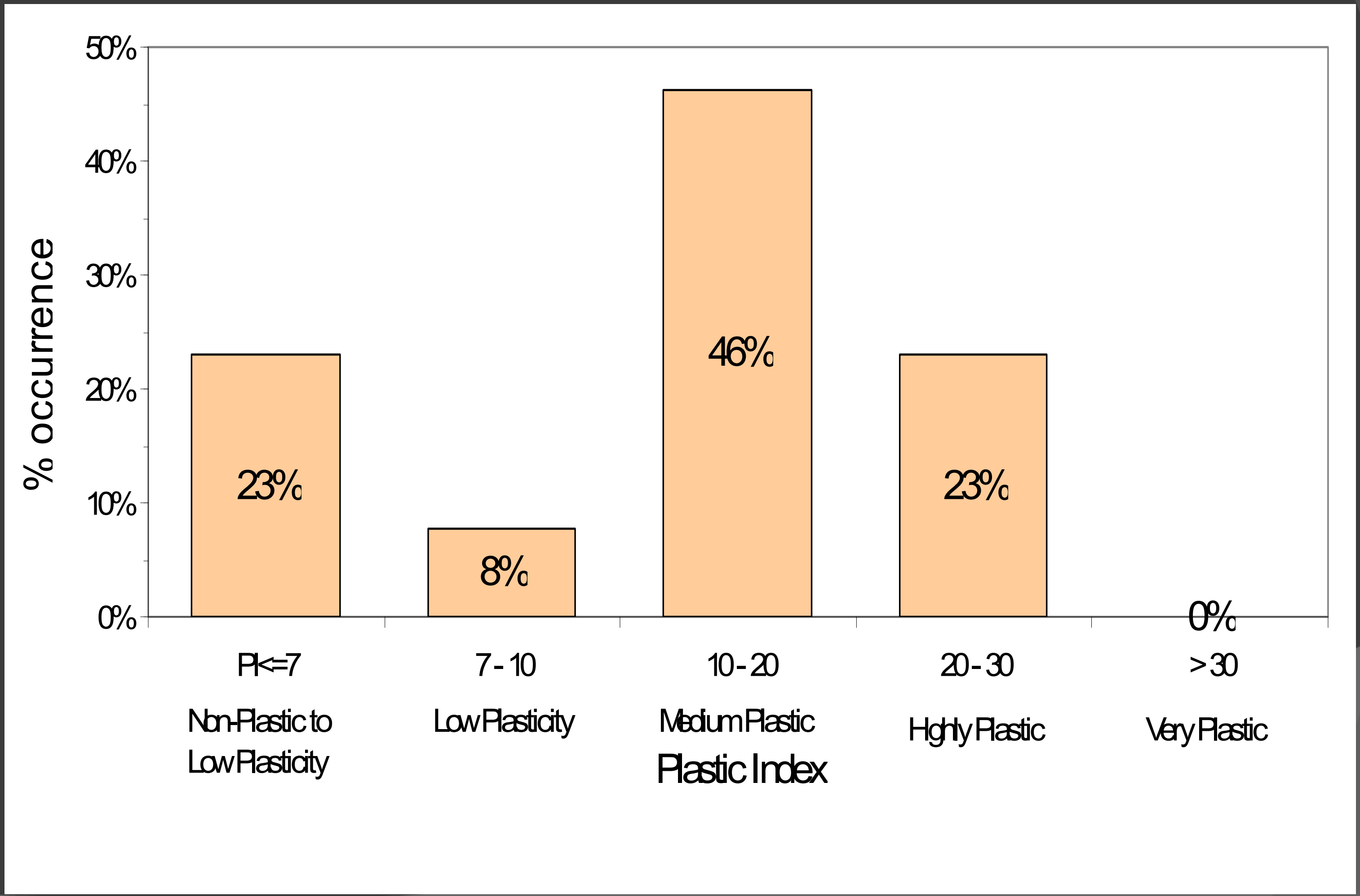
Other Mapping Inputs

Qal_1 – Stream alluvium 1

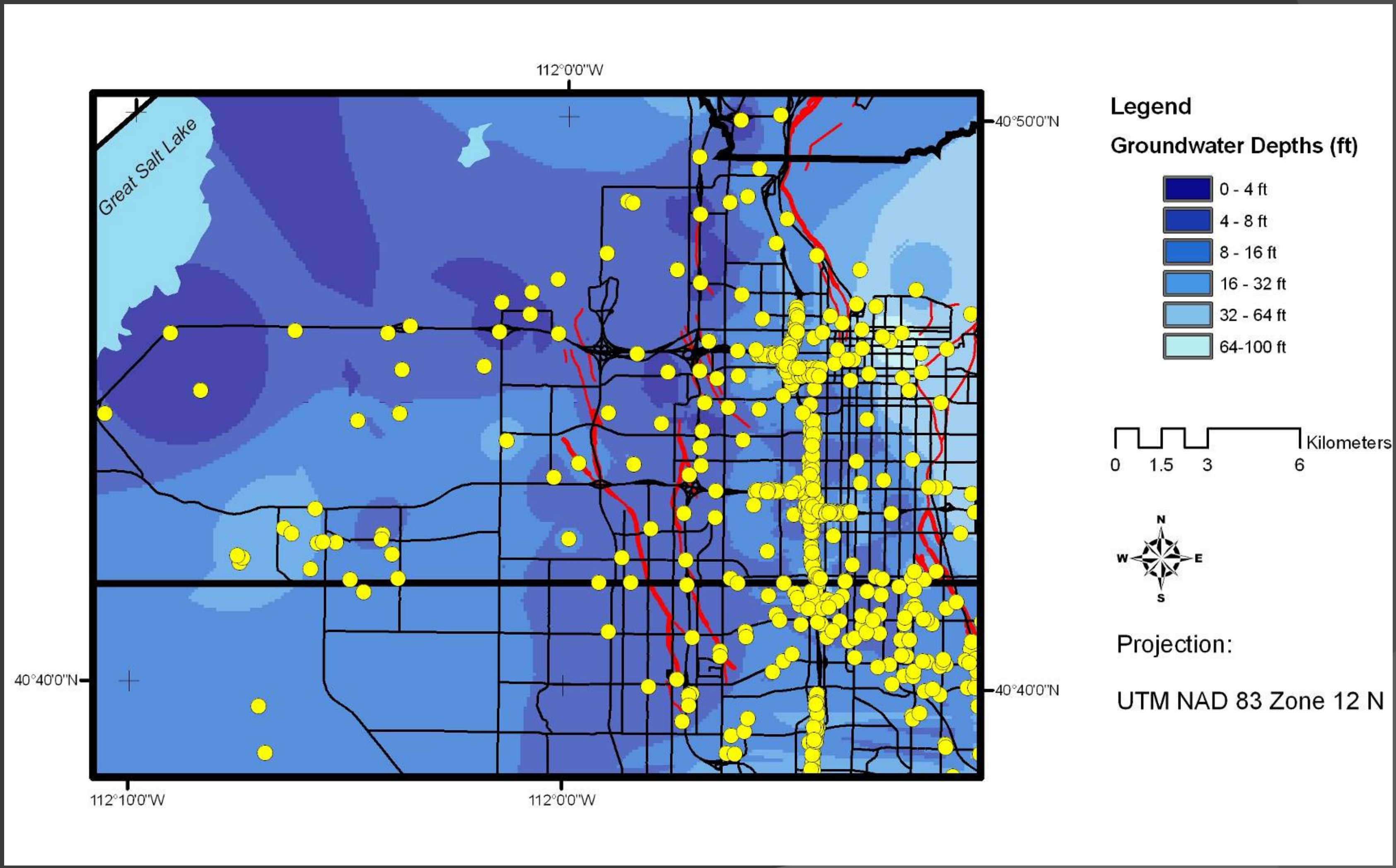


Other Mapping Inputs

Qal$_1$ – Stream alluvium 1

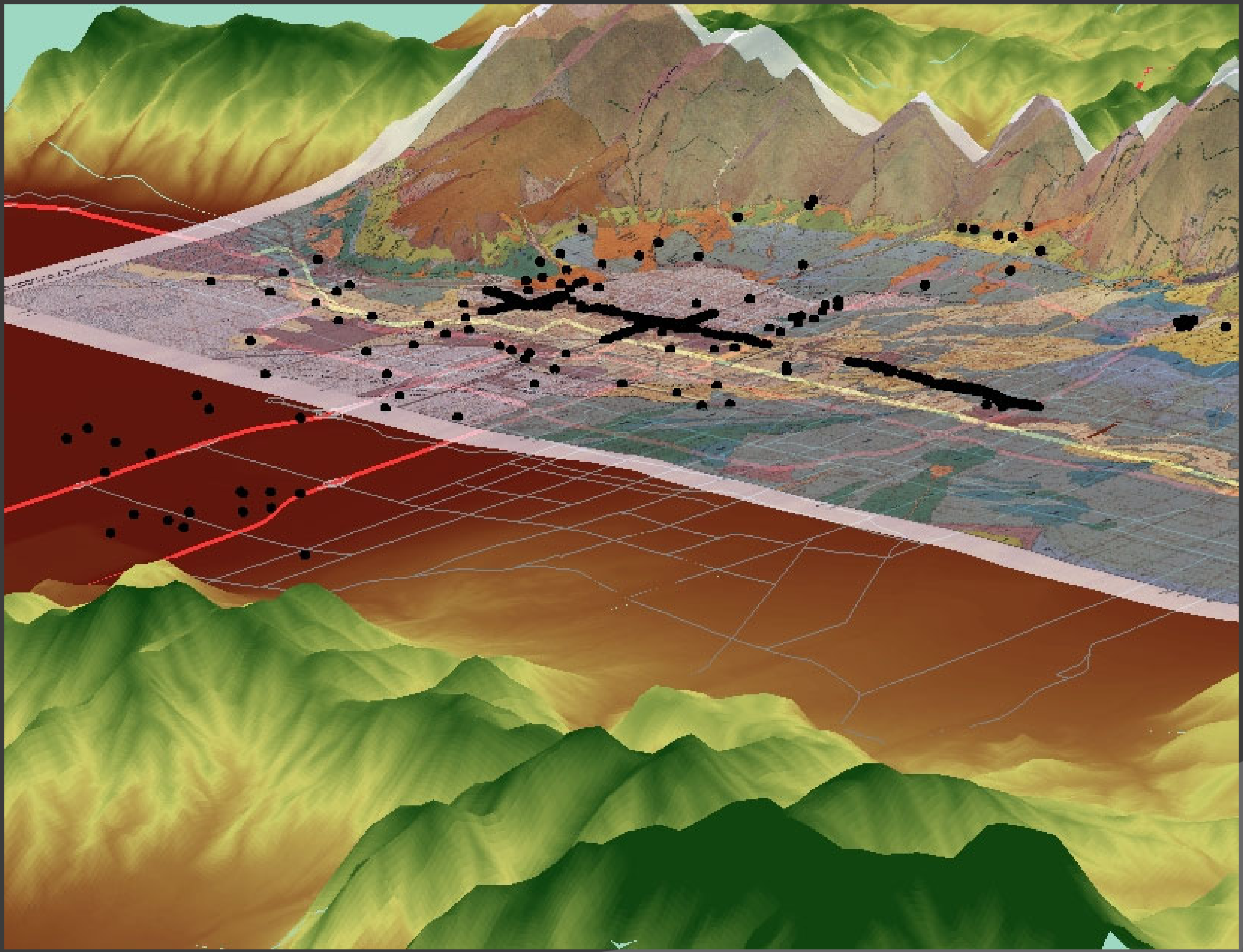


Other Mapping Inputs



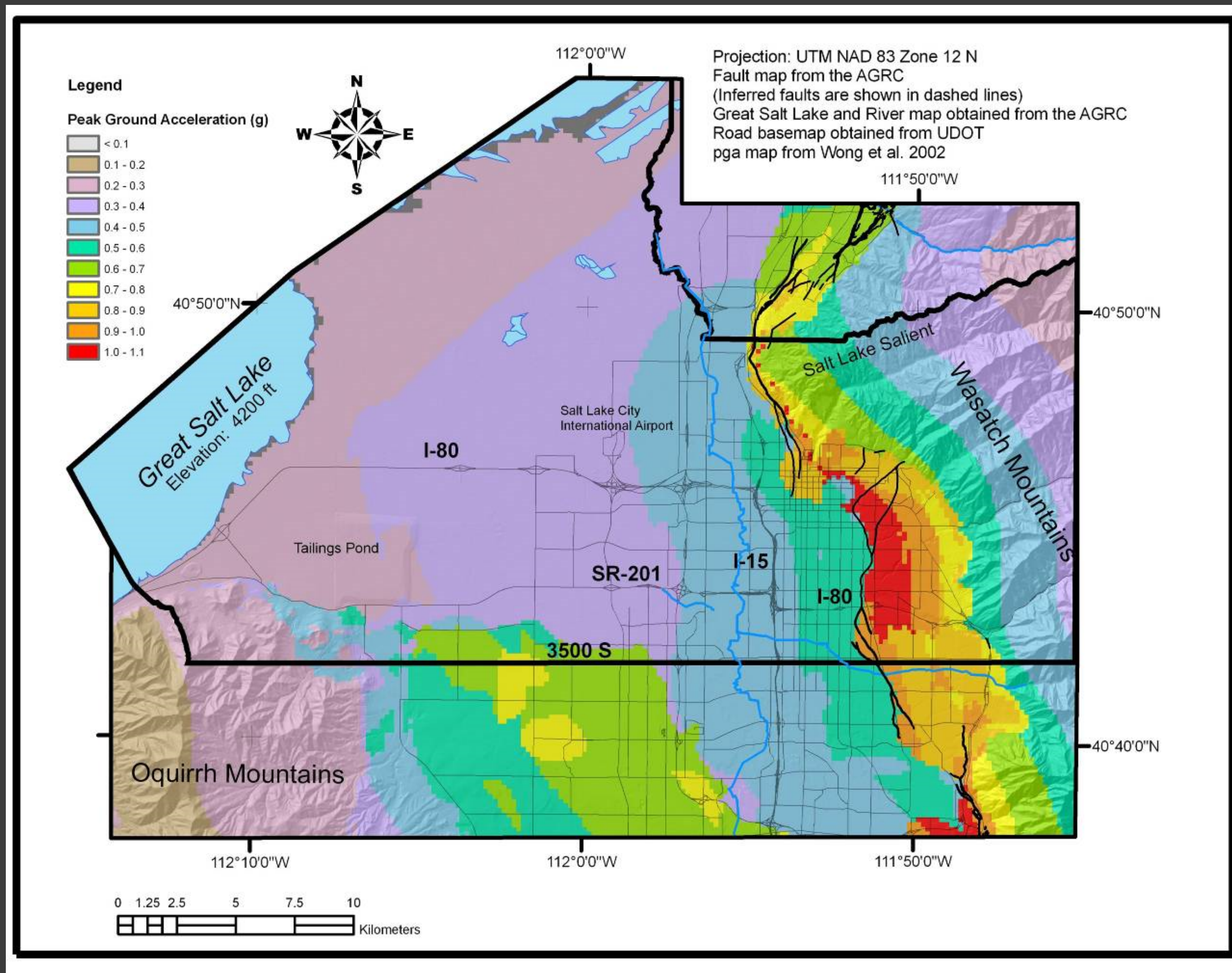
Groundwater Depth Map

Other Mapping Inputs



Digital Elevation Model

Other Mapping Inputs



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

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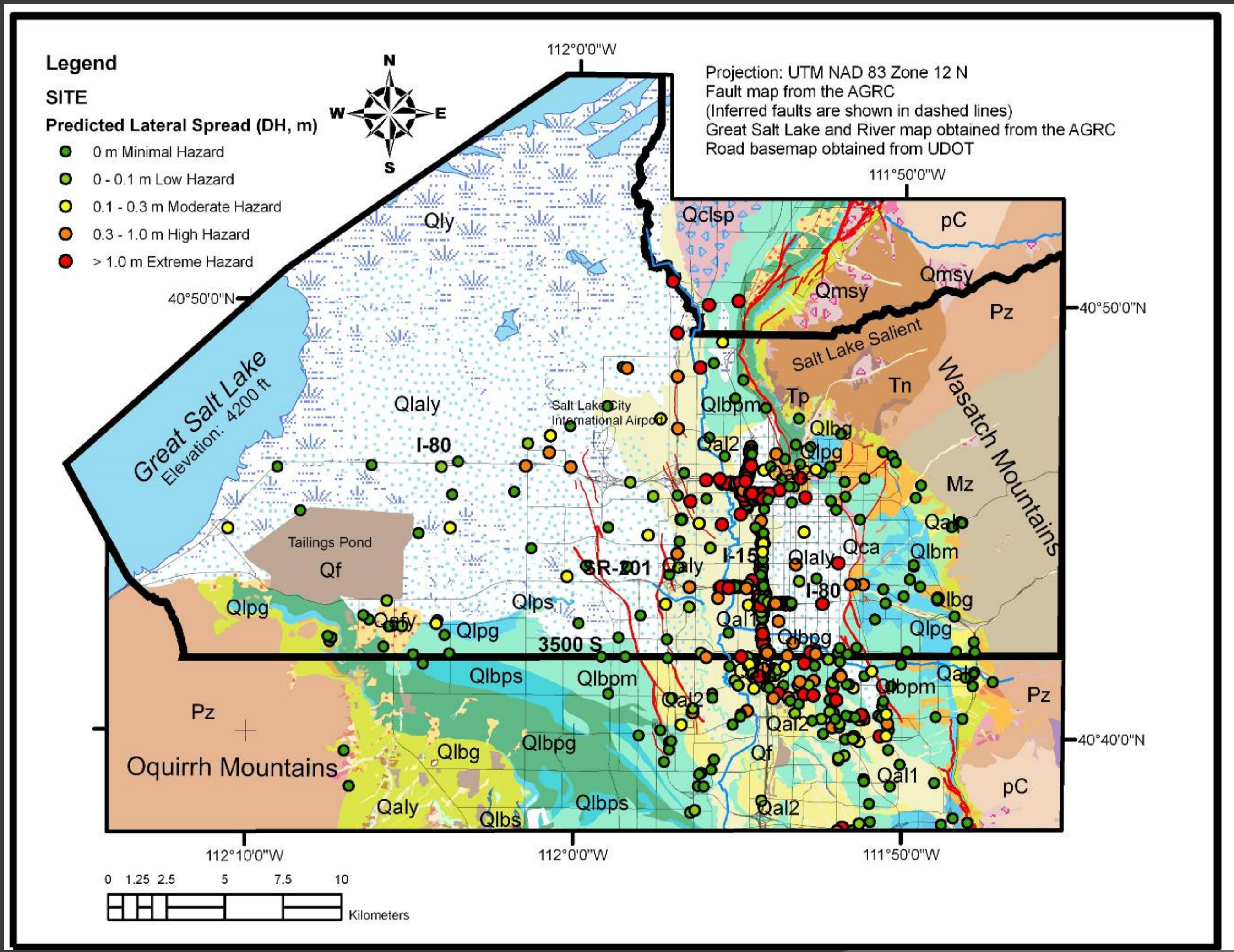
Map Creation



Predicted Lateral Spread Displacement at Boreholes

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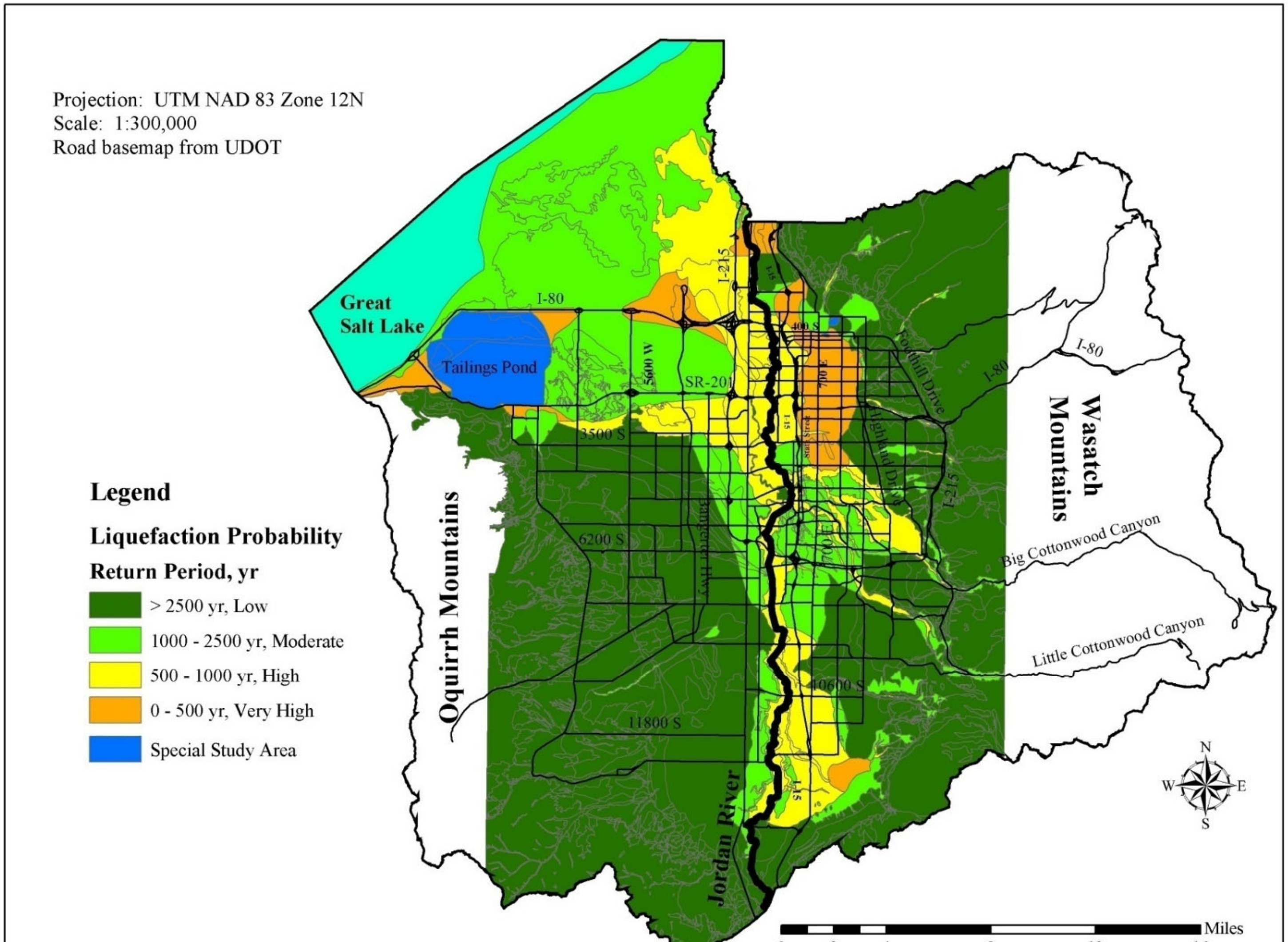
Map Examples – Liquefaction Potential (Aggregated)

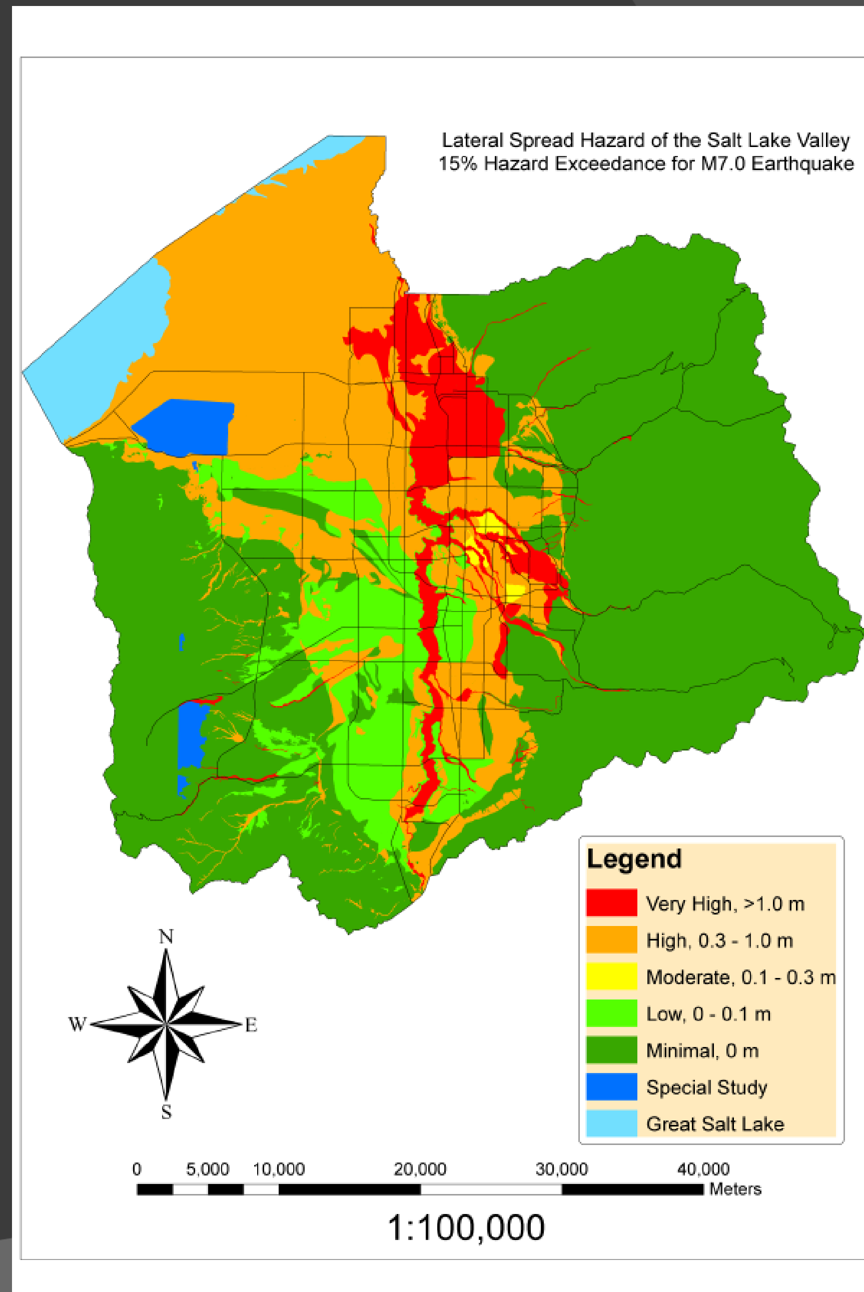


$$P(L) = \sum P[L \mid A,M] \; P[A, M]$$

Map Examples

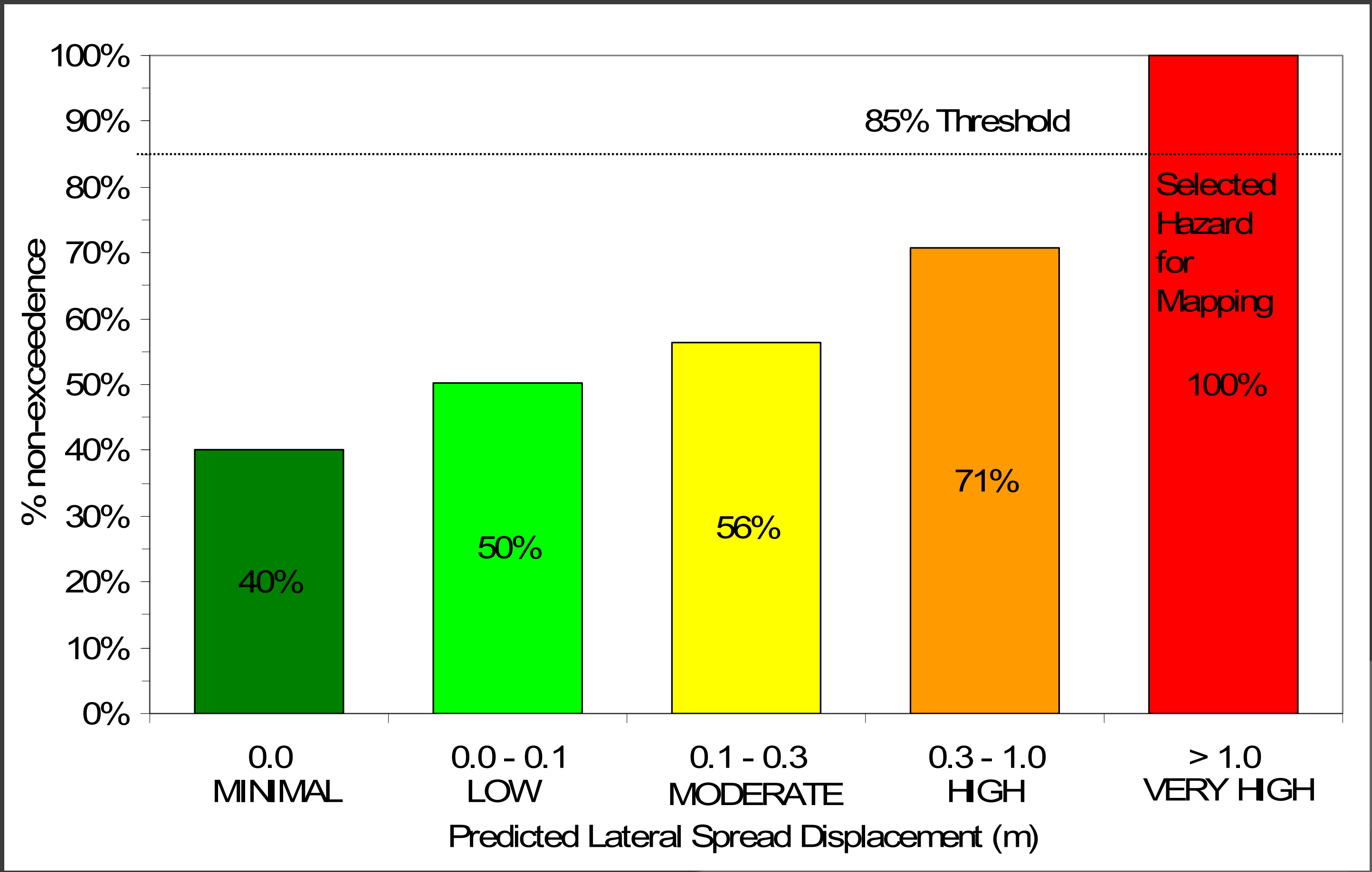
M 7.0 Lateral spread displacement map (15 percent chance of exceedance)

(Recommended for regulatory use)



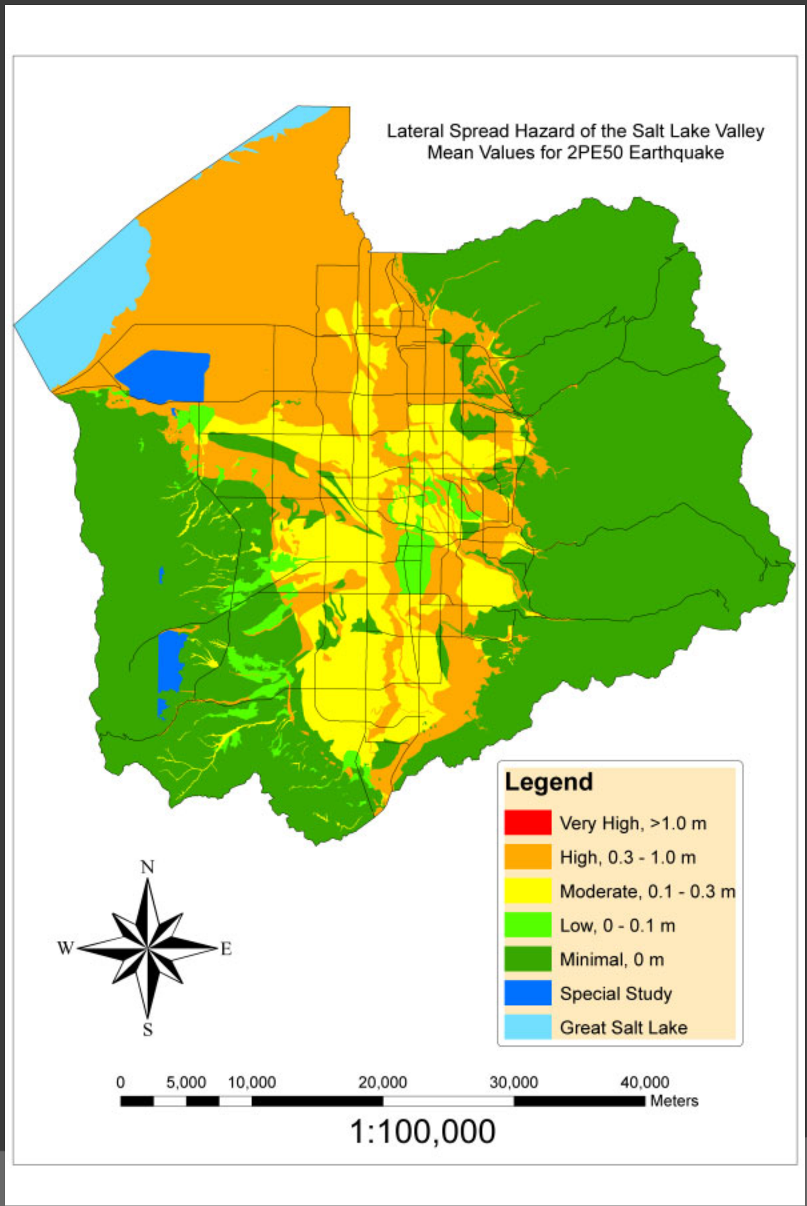
Map Examples

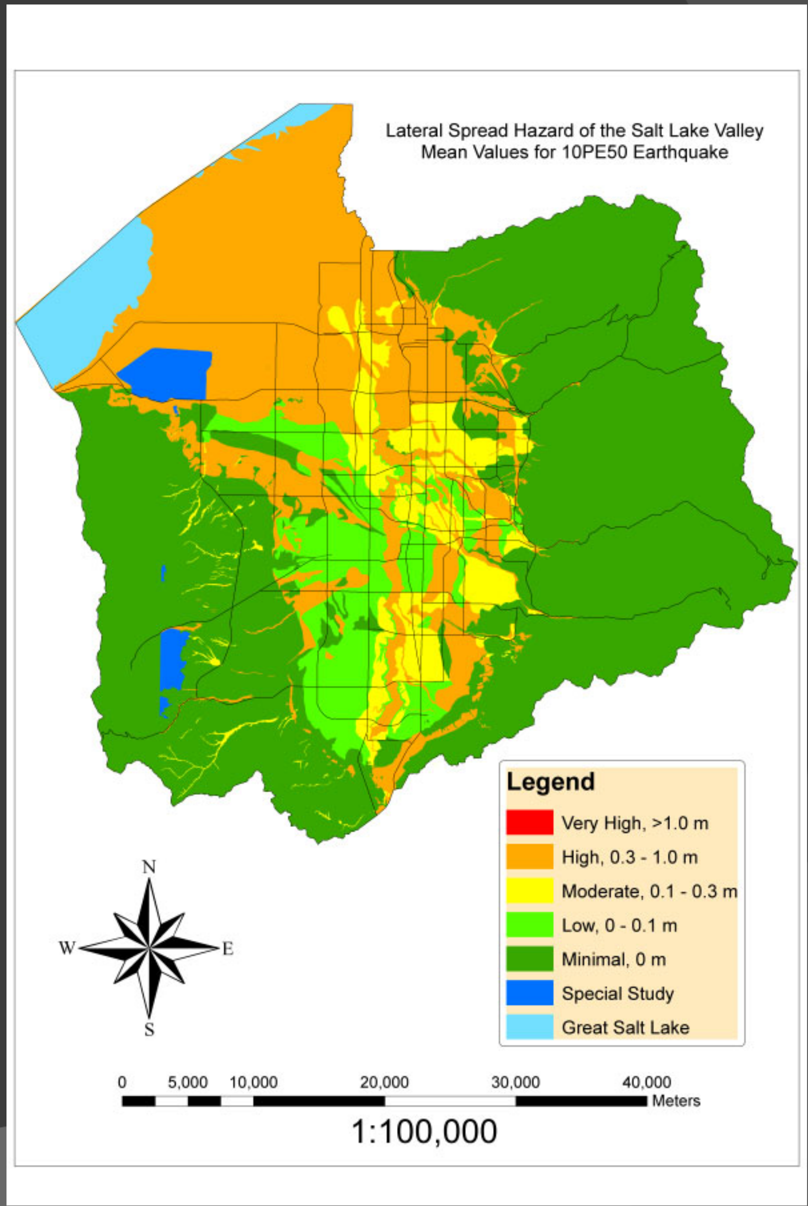
- Mapping 85% threshold (i.e., 15% or less chance of exceedance)



Cumulative histogram of lateral spread displacement

Map Examples
Lateral Spread or 2500 and 500-year scenarios

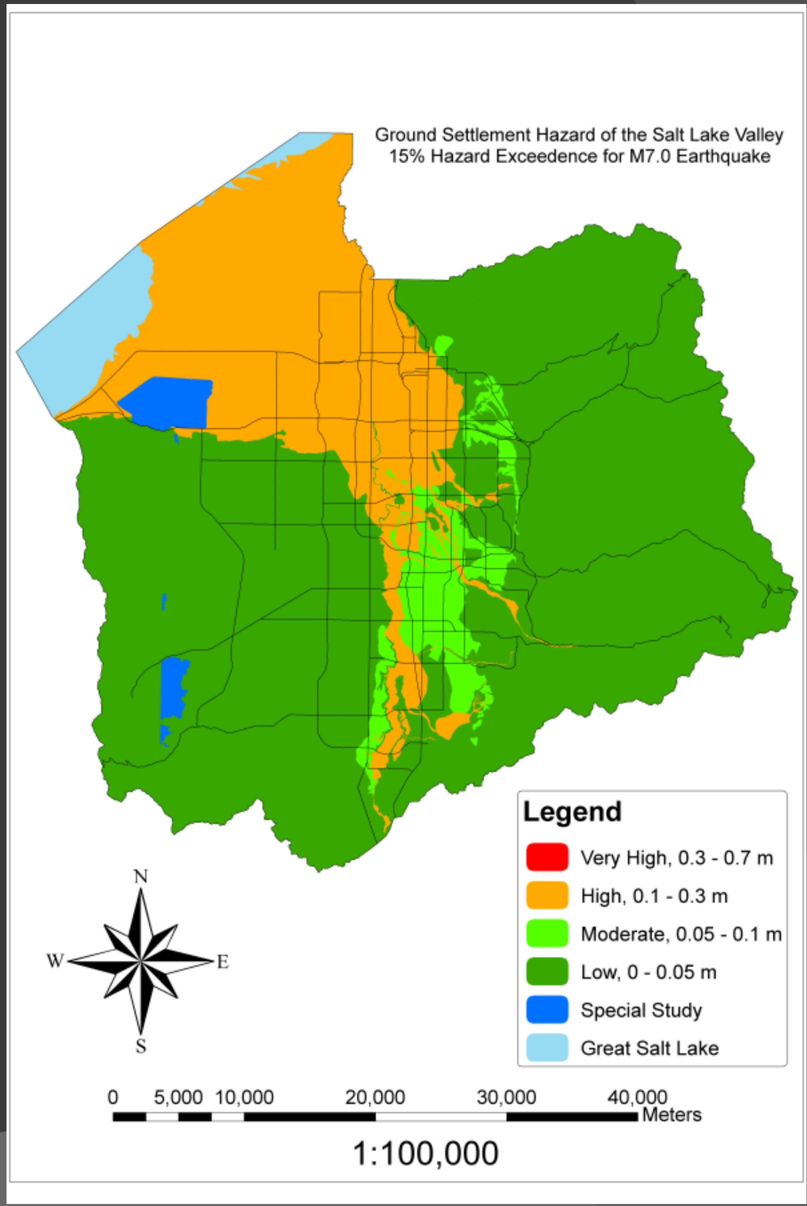




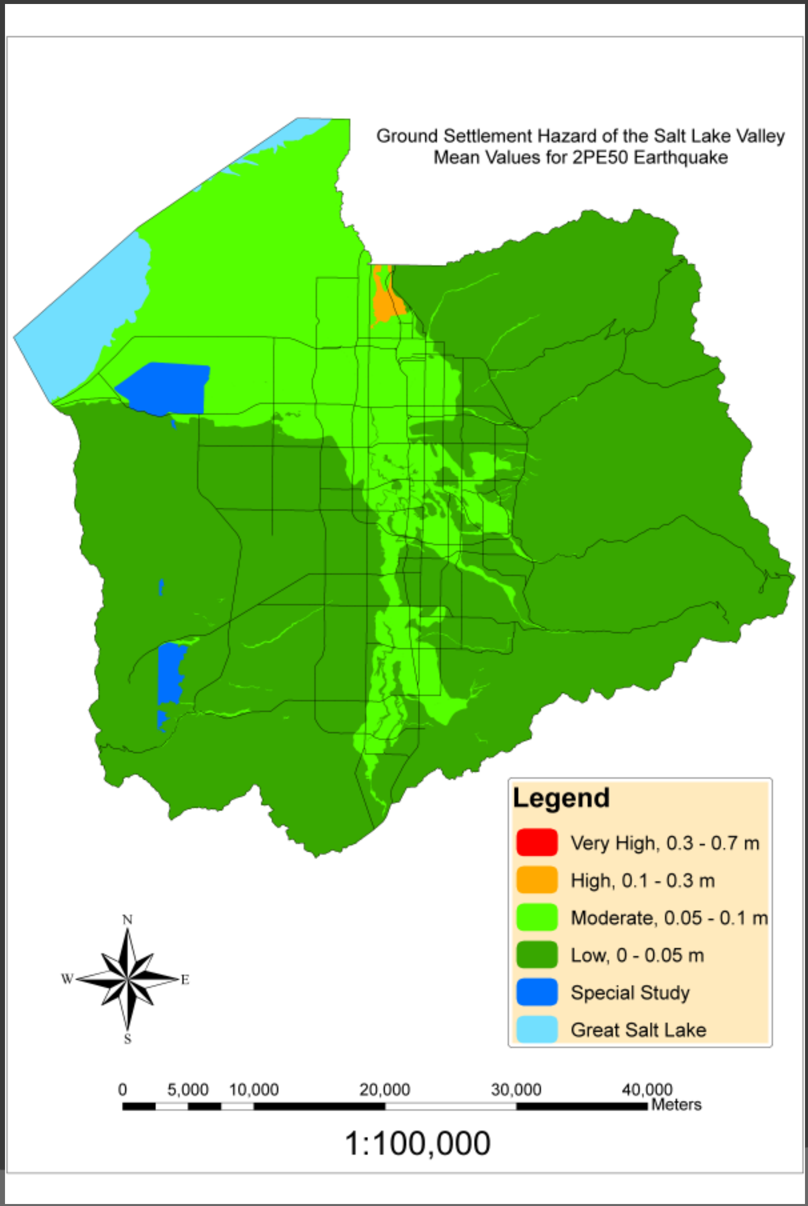
Map Examples

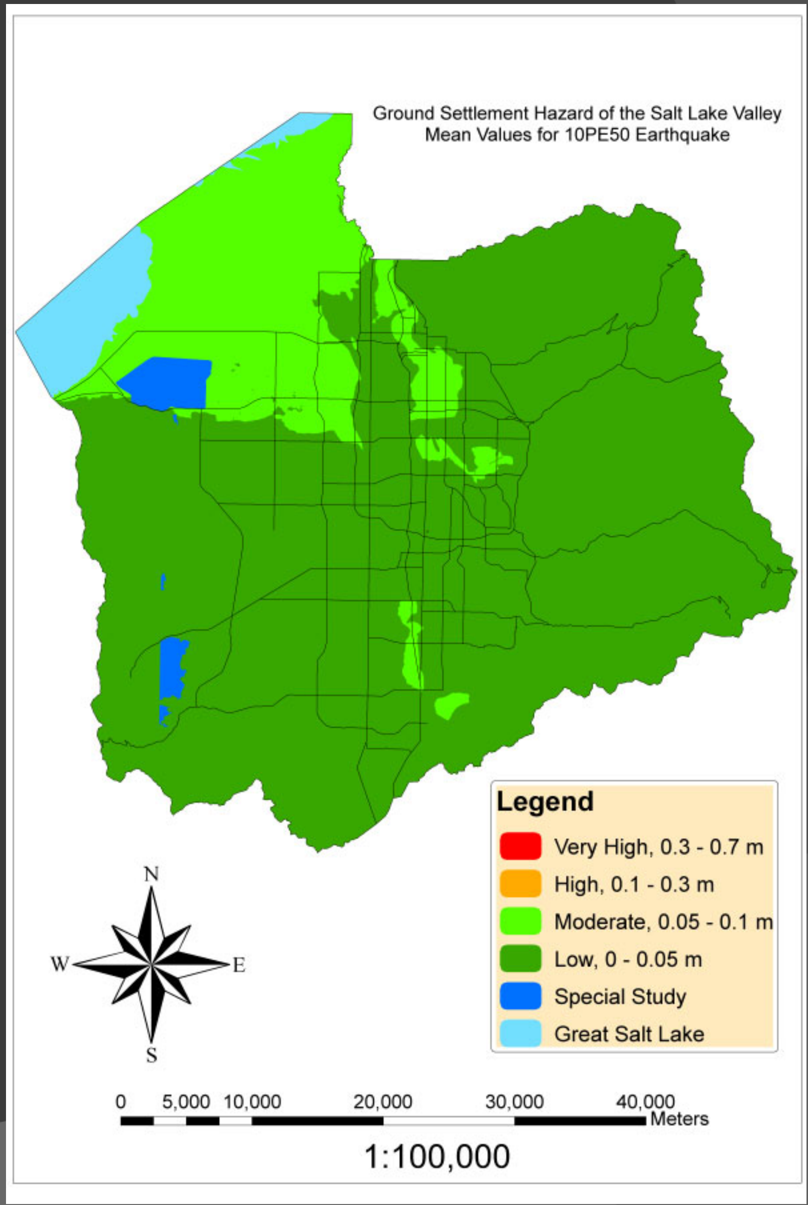
M 7.0 Ground Settlement Map (15 percent chance of exceedance)

(Recommended for regulatory use)



Map Examples
Ground Settlement Map for 2500 and 500-year scenarios





Mapping of Weber Co.

- Less geotechnical data
  - Improve methods of combining geotechnical data with surficial geology
  - Better methods for including CPT data
- Generalize displacement regression model
- Perform uncertainty analysis
- Improve the influence of topography

Estimating Liquefaction Potential

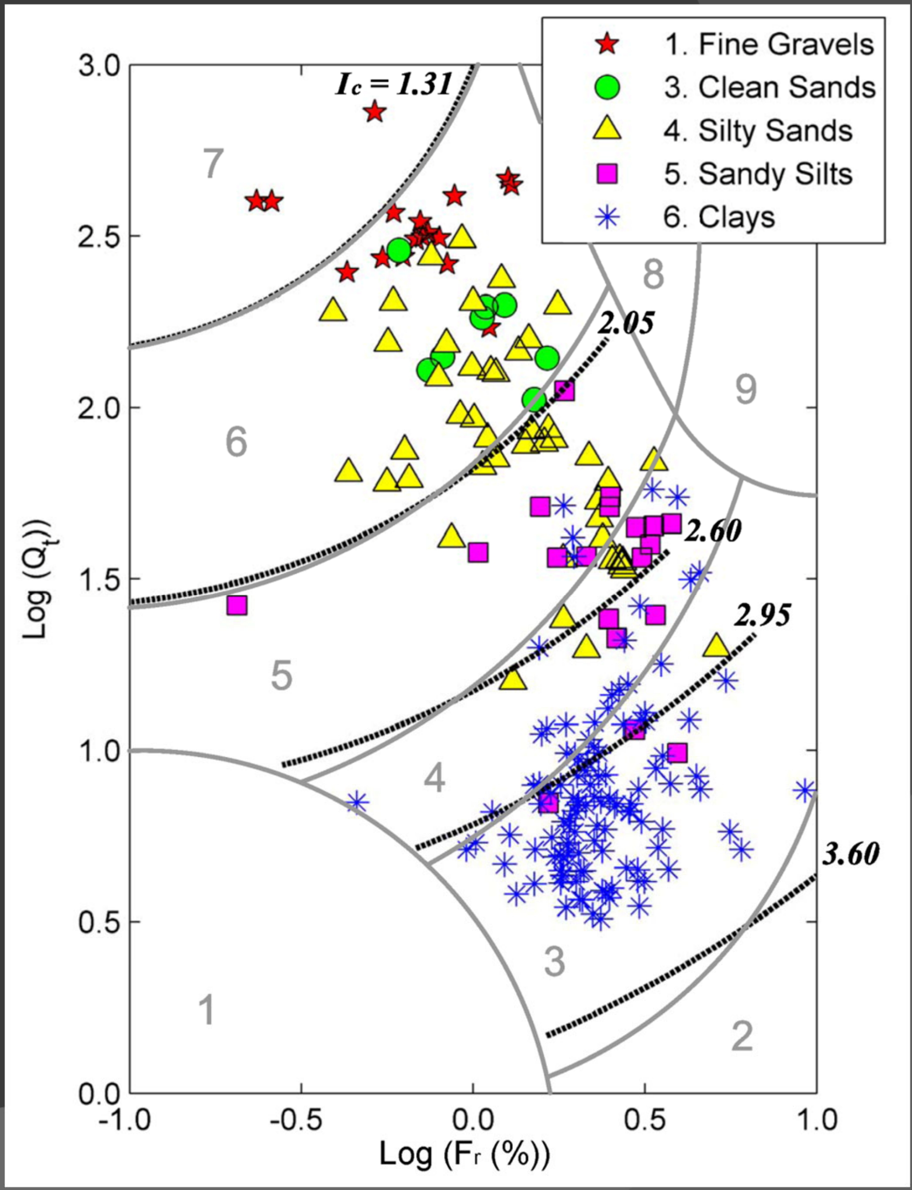
Zone	Soil Behaviour Type (SBT)
1	*Sensitive fine-grained*
2	*Clay - organic soil*
3	*Clays: clay to silty clay*
4	*Silt mixtures: clayey silt & silty clay*
5	*Sand mixtures: silty sand to sandy silt*
6	*Sands: clean sands to silty sands*
7	*Dense sand to gravelly sand*
8	*Stiff sand to clayey sand**
9	*Stiff fine-grained**

** Overconsolidated or cemented*

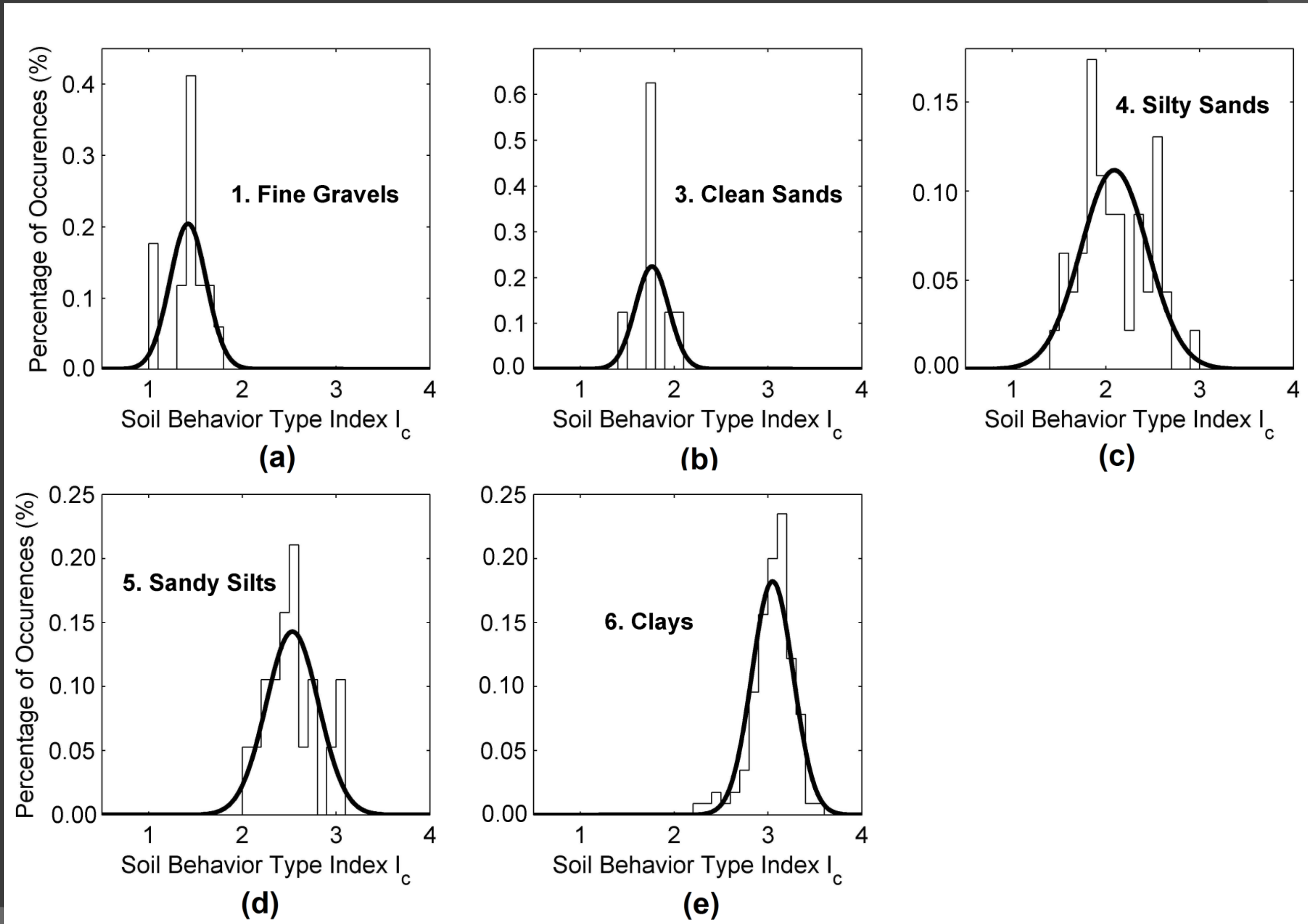
$$I_c = [(3.47 - LogQ_{tn})^2 + (LogF_r + 1.22)^2]^{0.5}$$

Robertson (1990) Soil Behavior Type Chart

- Boundaries of each zone estimated by circles with radius = I_c



Estimation of Liquefaction Potential



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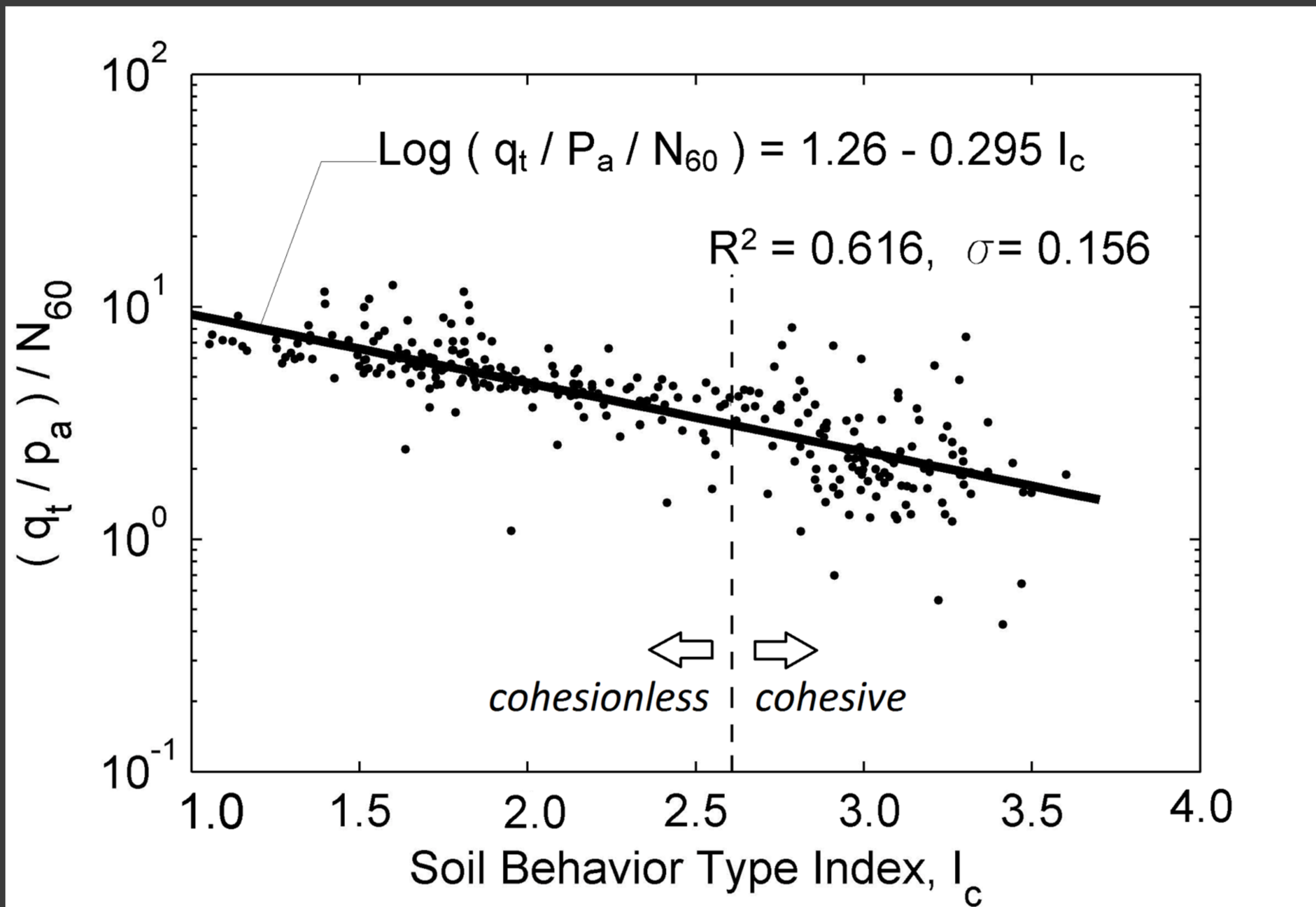
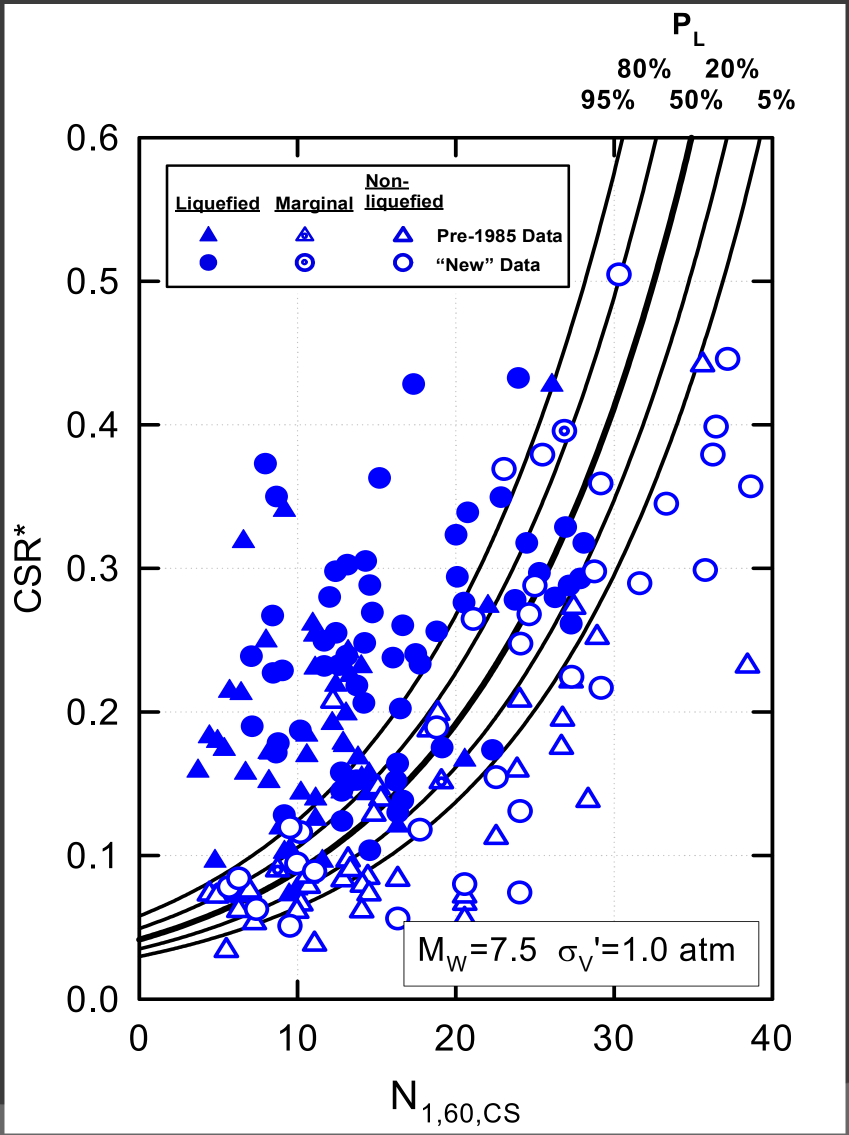


Estimation of Liquefaction Potential



Recommended "Probabilistic" SPT-Based Liquefaction
Triggering Correlation

(For MW=7.5 and sv'=1.0 atm)

(Seed et al. 2003)

Estimation of Ground Displacement

Gillins and Bartlett (2013) Empirical Model

$$LogD_H = \begin{array}{c} b_o + b_{off}\alpha + b_1 M + b_2 LogR^* + b_3 R + b_4 LogW + b_5 LogS + \\ + b_6 LogT_{15} + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5 \end{array}$$

x_i = *the portion (decimal fraction) of* T_{15} *in a borehole that has a soil index corresponding to the table below*

Soil Index *(SI)*	Typical Soil Description in Case History Database	General USCS Symbol
1	Silty gravel, fine gravel	GM
2	Coarse sand, sand and gravel	GM-SP
3	Medium to fine sand, sand with some silt	SP-SM
4	Fine to very fine sand, silty sand	SM
5	Low plasticity silt, sandy silt	ML
6	Clay (not liquefiable)	CL-CH

Estimation of Ground Displacement

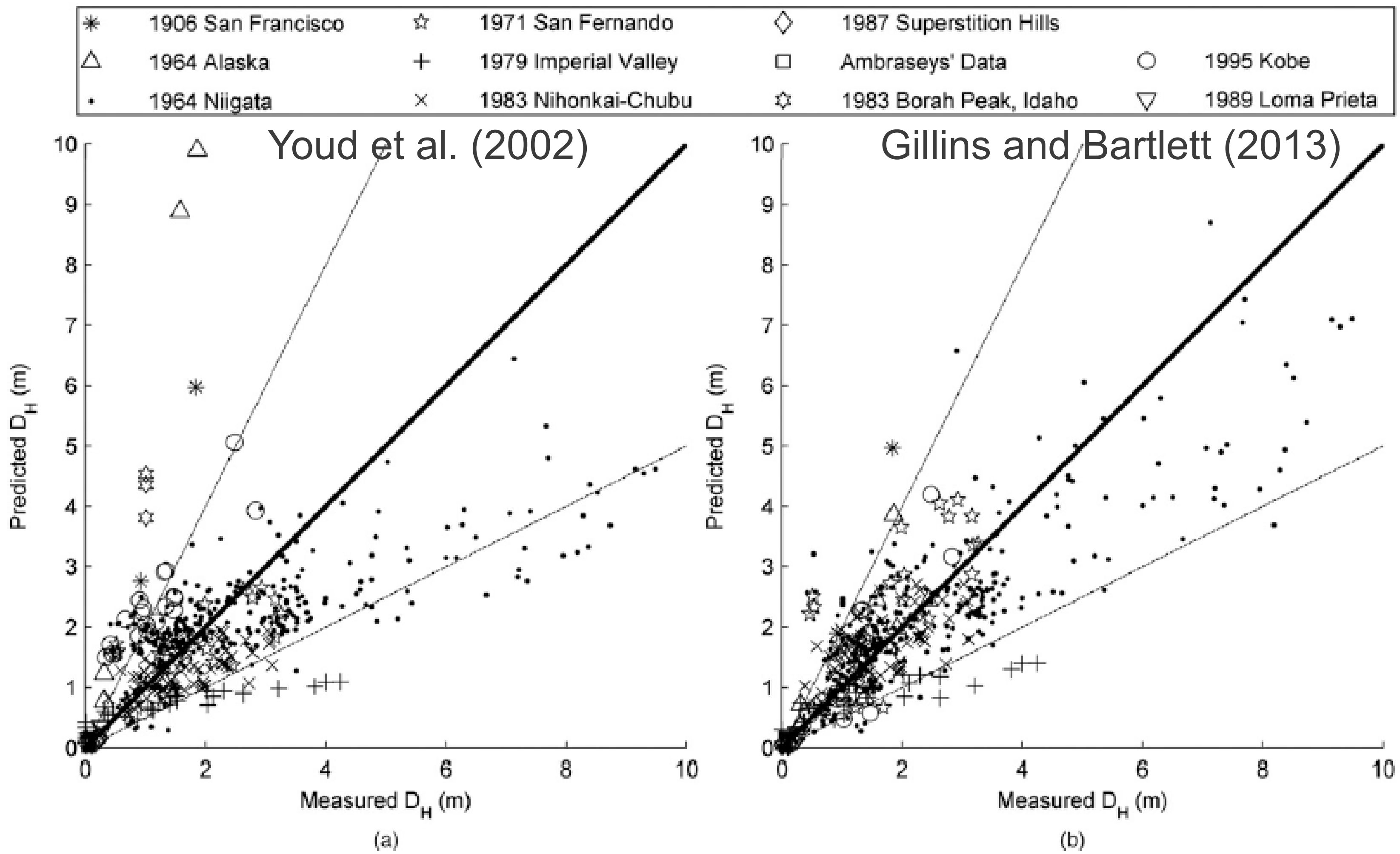
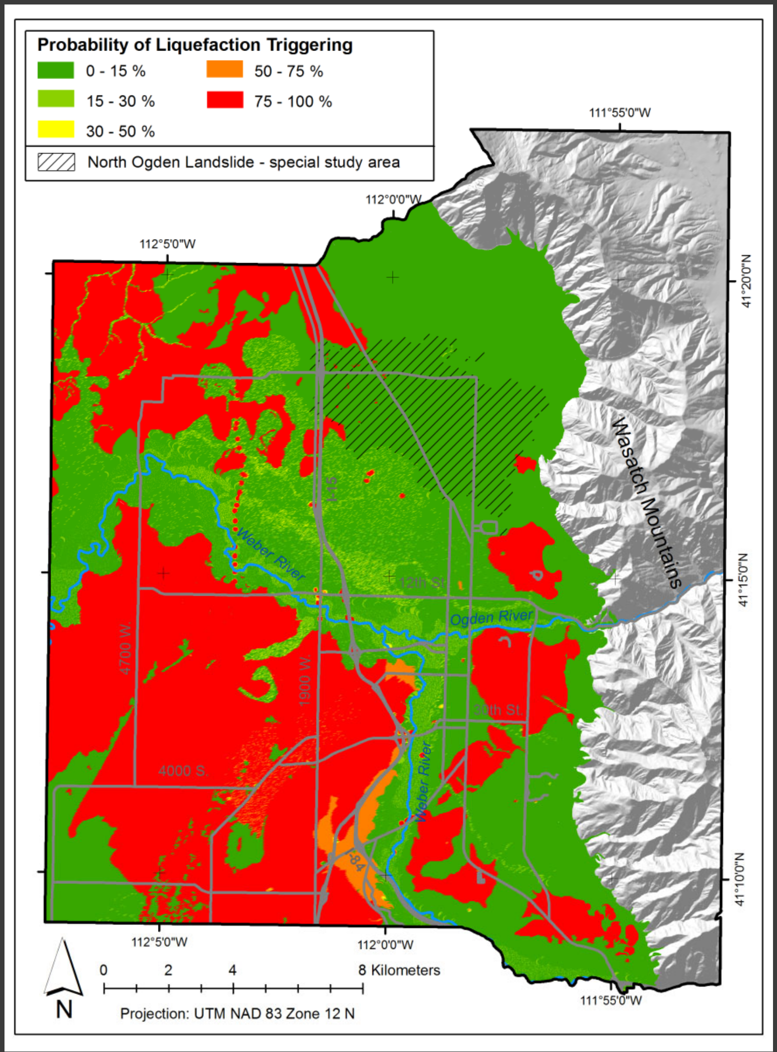
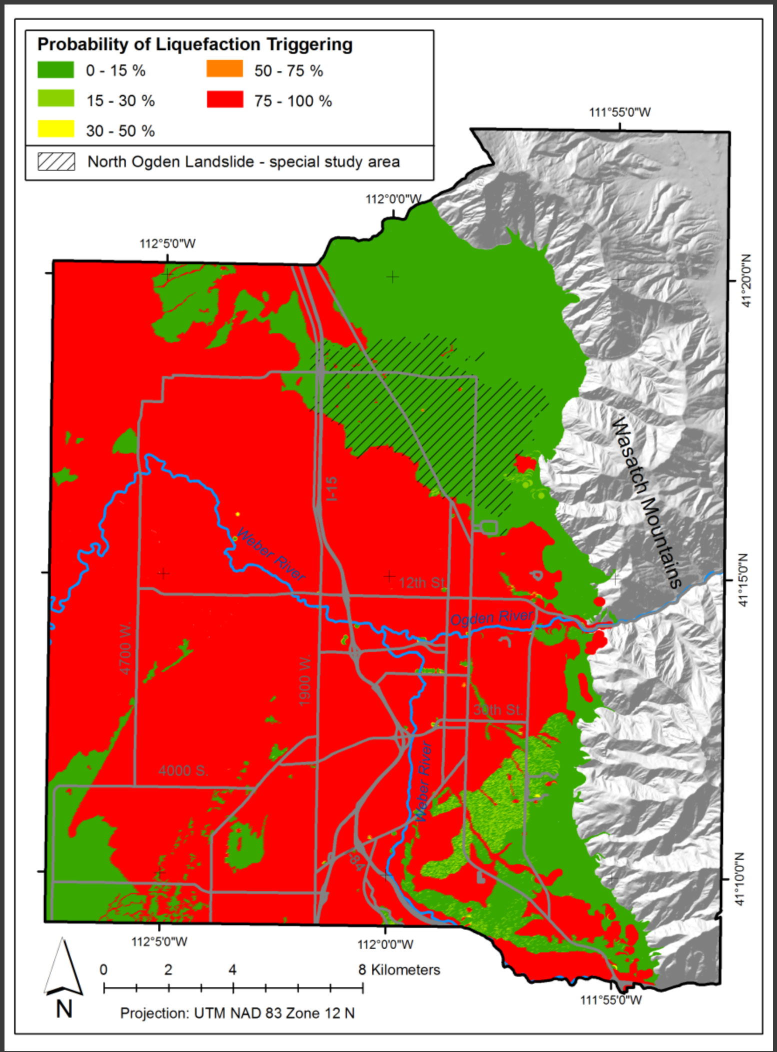


Fig. 1. Predicted lateral spread displacement using (a) Eq. (3) or (b) Eq. (4), versus measured lateral spread displacement from the case history database of Youd et al. (2002)

Liquefaction Potential Maps

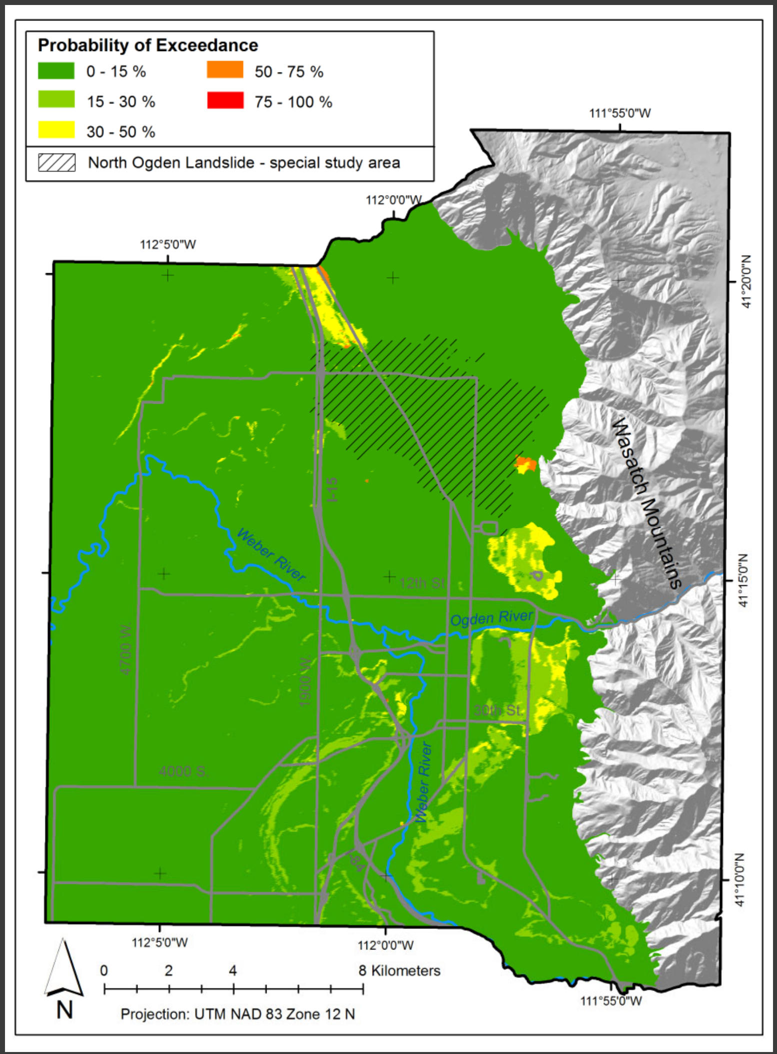


Median probabilities of P_L, 500-year seismic event

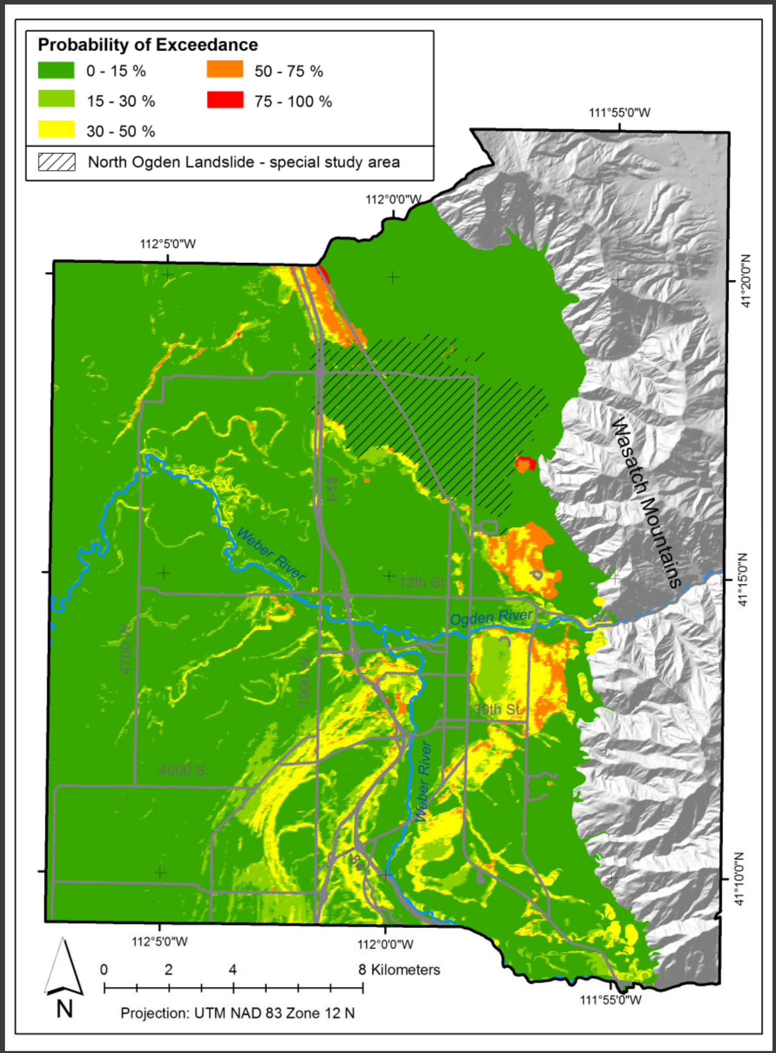


Median probabilities of P_L, 2,500-year seismic event

Lateral Spread Hazard Maps

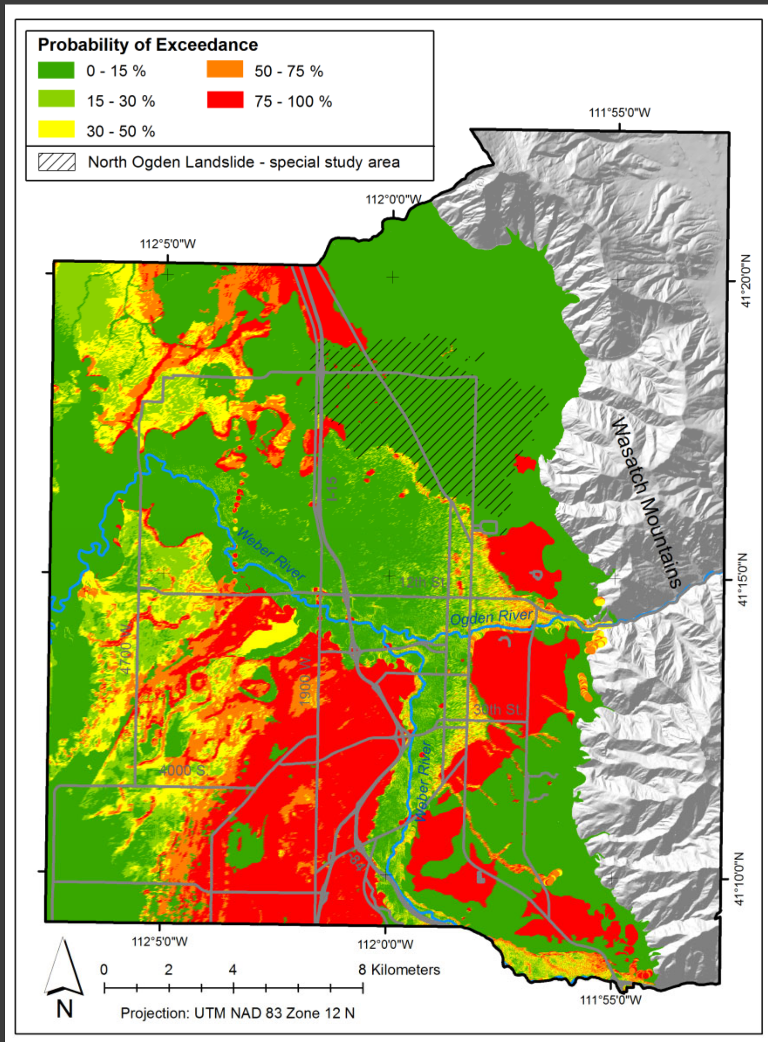


Median probabilities of exceeding 0.3 m, 500-year event

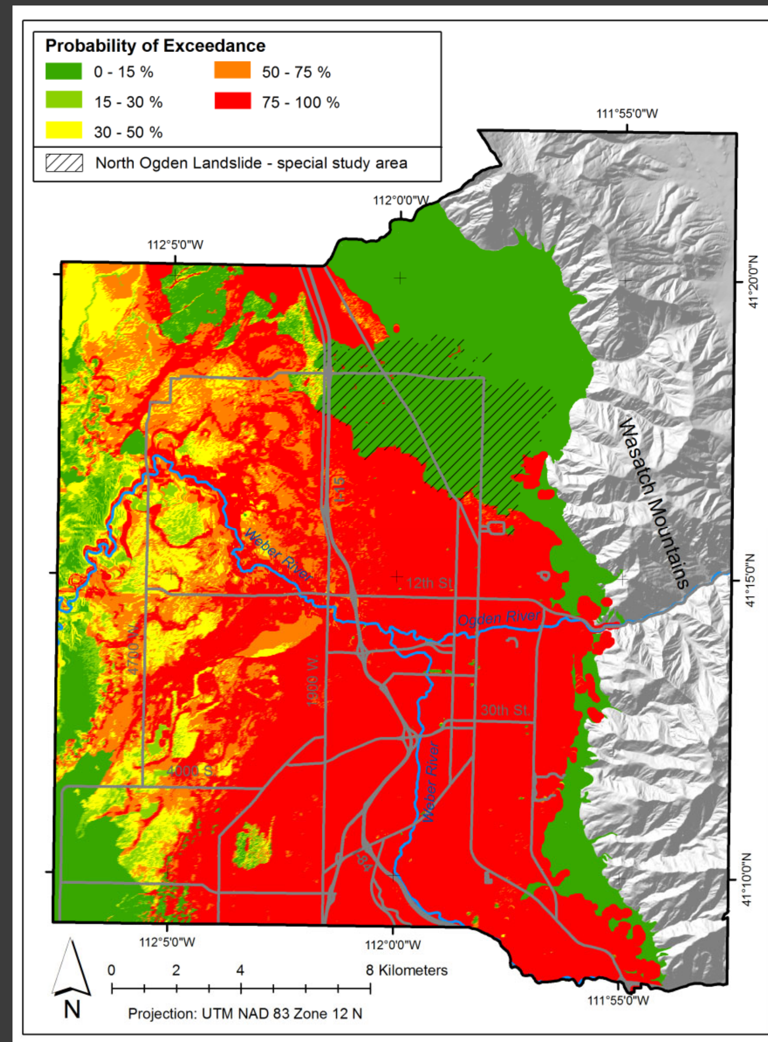


84th percentile probabilities, of exceeding 0.3 m, 500-year event

Lateral Spread Hazard Maps



Median probabilities of exceeding 0.3 m, 2,500-year event



84th percentile probabilities, of exceeding 0.3 m, 2,500-year event

For more information:

http://www.civil.utah.edu/~bartlett/ULAG/

Multilinear Regression Equations for Predicting Lateral Spread Displacement from Soil Type and Cone Penetration Test Data

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