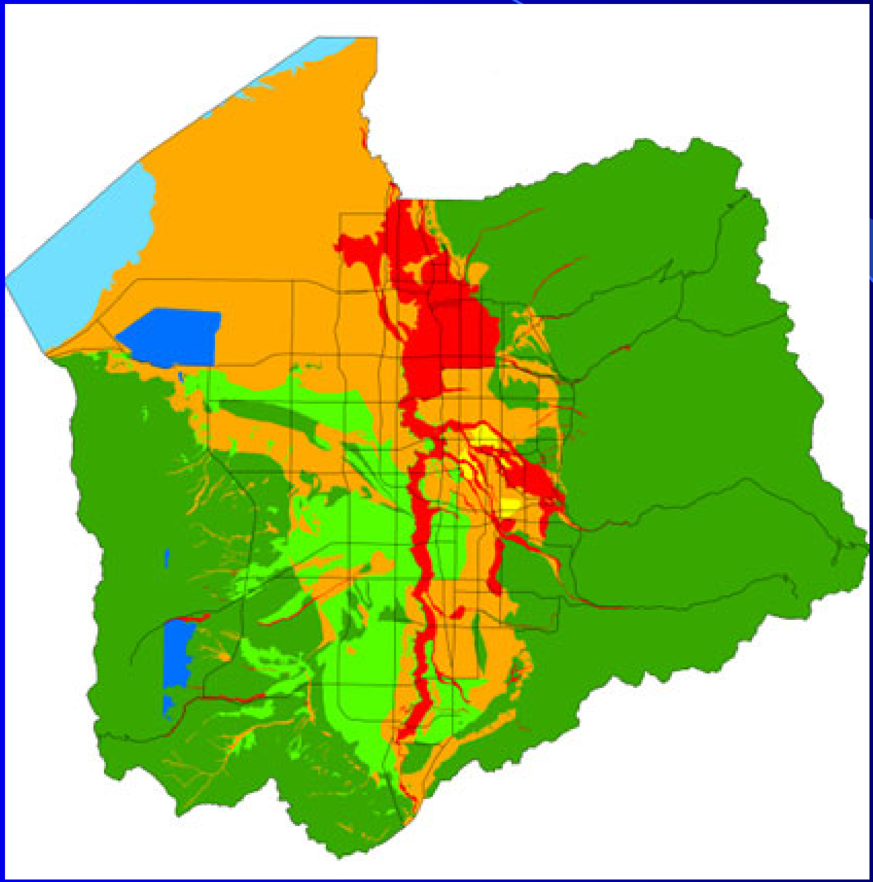
Implementation of Risk-Based Liquefaction Maps in Hazard Ordinances and Risk-Based Decision Making



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Overview

- Hazard Mitigation Grant Program (HMGP)
  - Federal Emergency Management Agency (FEMA)
  - Administered by the State of Utah Department of Public Safety Division of Emergency Management

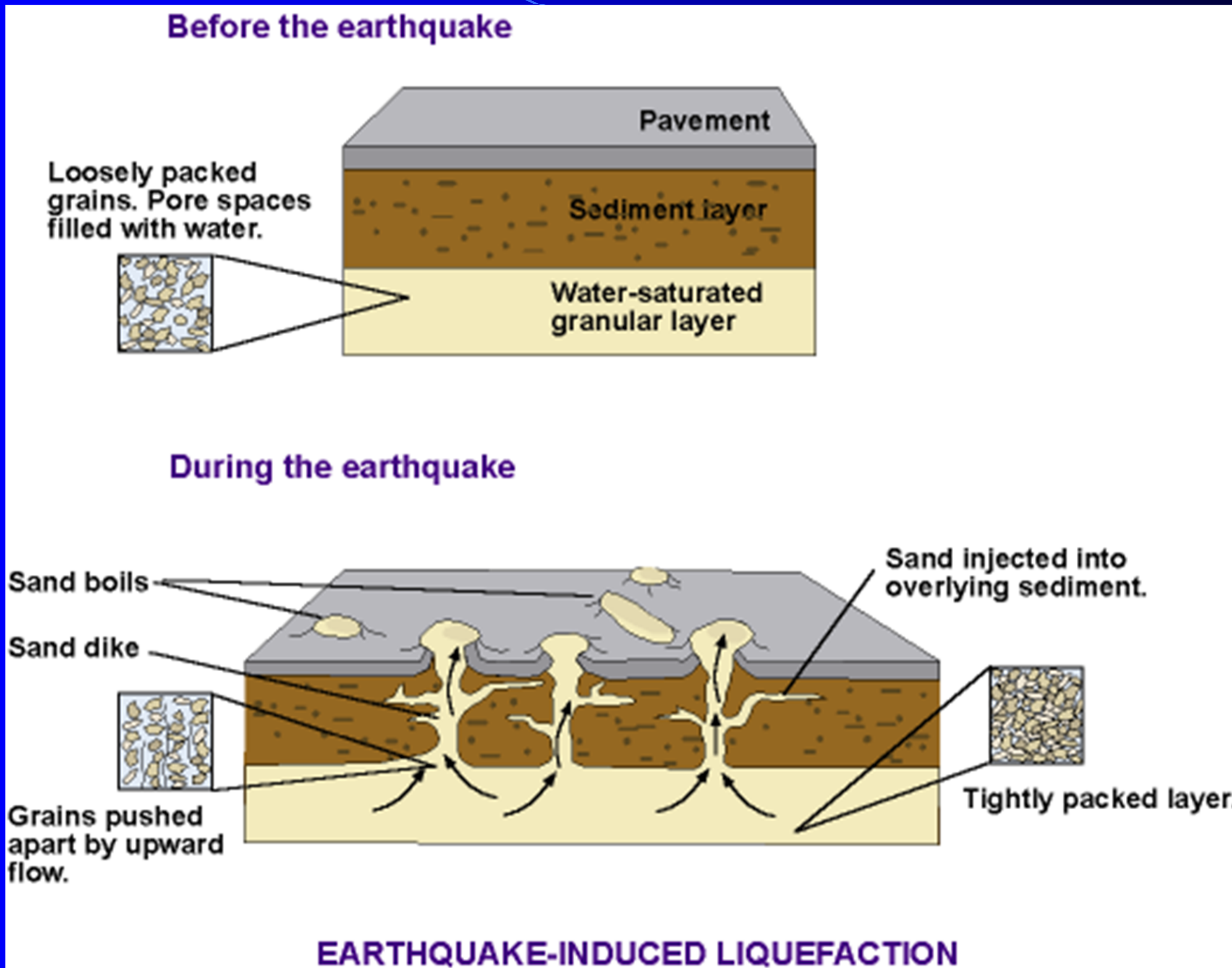
Objectives

- Develop a new model ordinance for liquefaction hazards based on input and feedback from municipalities, technical advisory groups, and others.
- 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.
- Develop methods to apply the liquefaction hazard maps to assess post-event traffic interruptions resulting from liquefaction-induced damage
- Educate the next generation of Utahans about earthquake hazards by focusing on a secondary education outreach curriculum.

Topics

- **Introduction to Liquefaction**
- Performance Base or Risk-Based Ordinances
- Liquefaction Mapping Efforts
- Modeling of Liquefaction Impacts to Traffic
- Educational Outreach

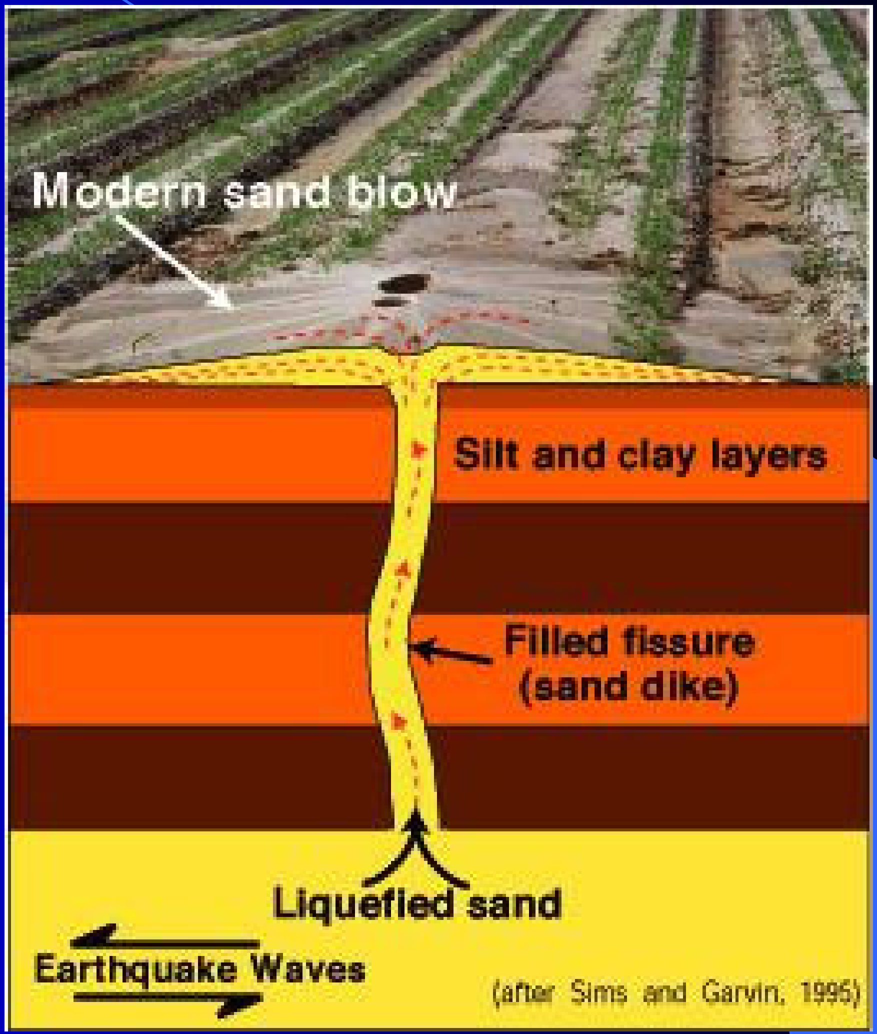
Liquefaction



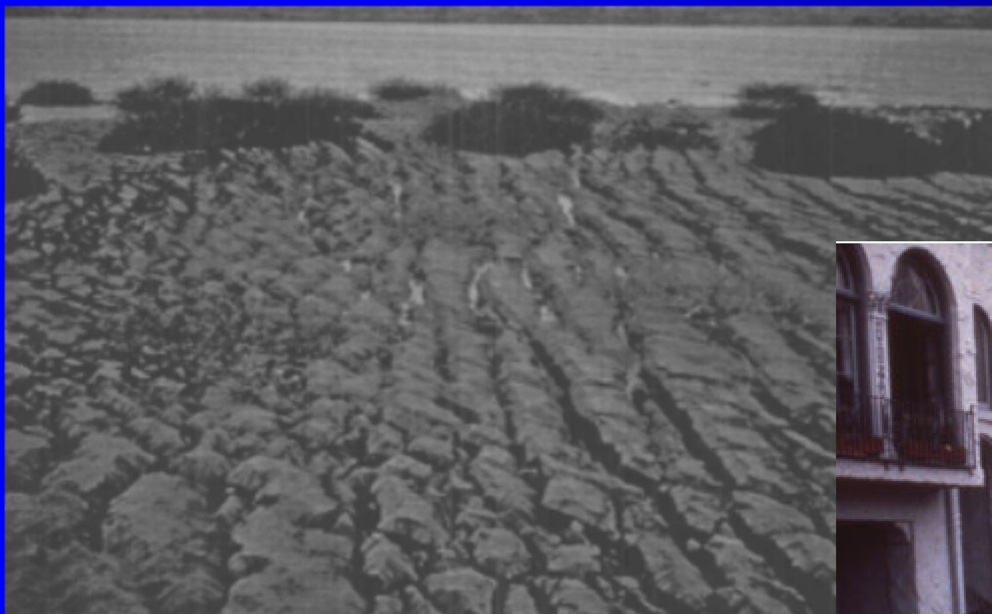
What is liquefaction?

Types of Liquefaction Damage

Sand Blow or Sand Volcano



Types of Liquefaction Damage



Ground Oscillation

Marina District, San Francisco,
1989 Loma Prieta Earthquake

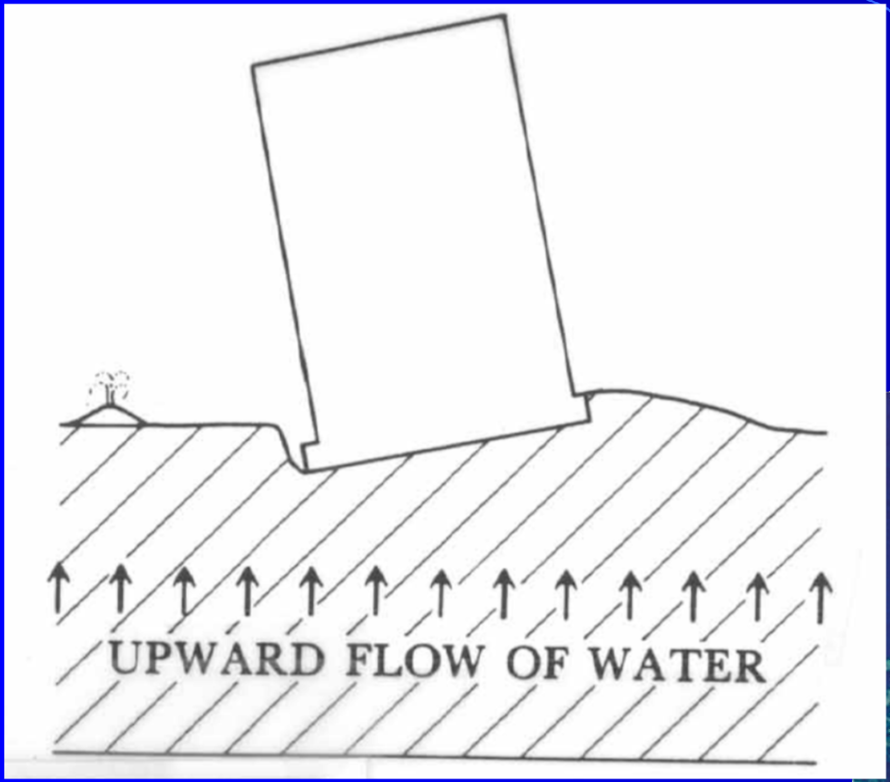
Types of Liquefaction Damage

2011 Tohoku Earthquake

Ground Settlement

2010 Christchurch Earthquake

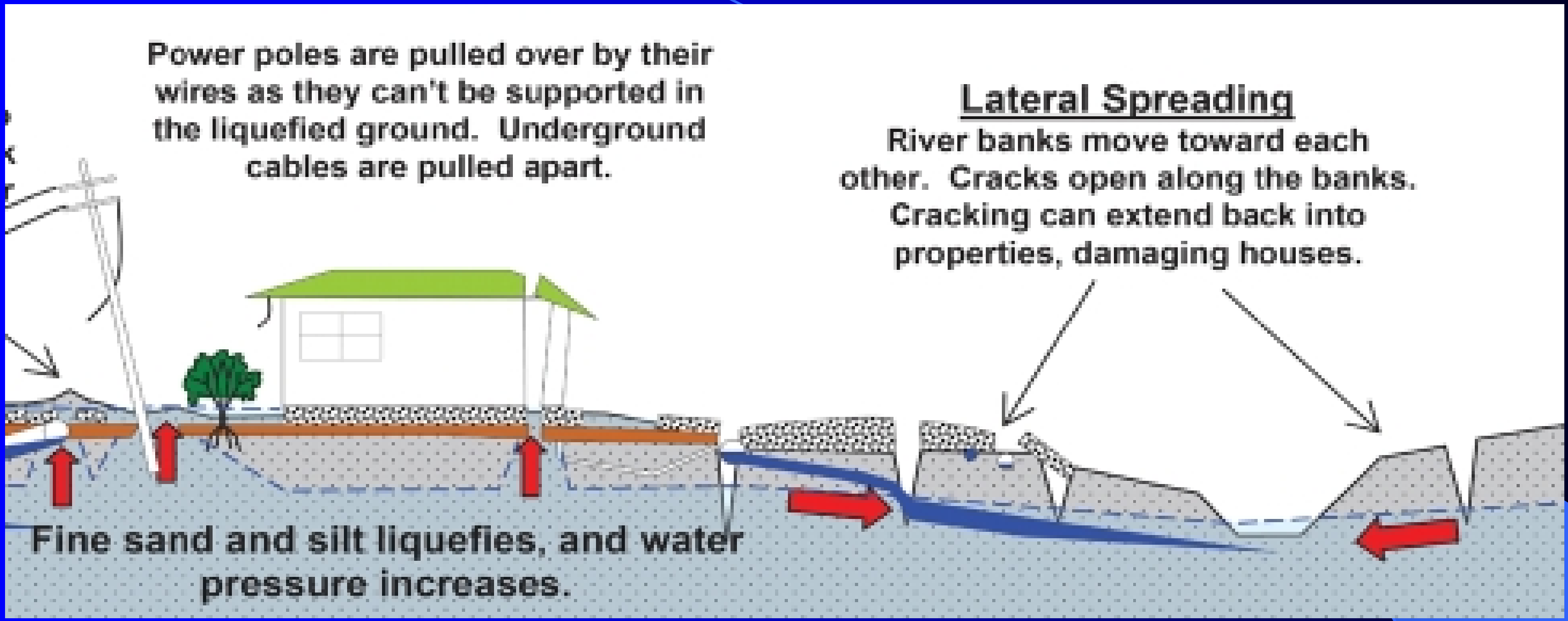
Types of Liquefaction Damage



Bearing Capacity Failure

1964 Niigata, Japan Earthquake

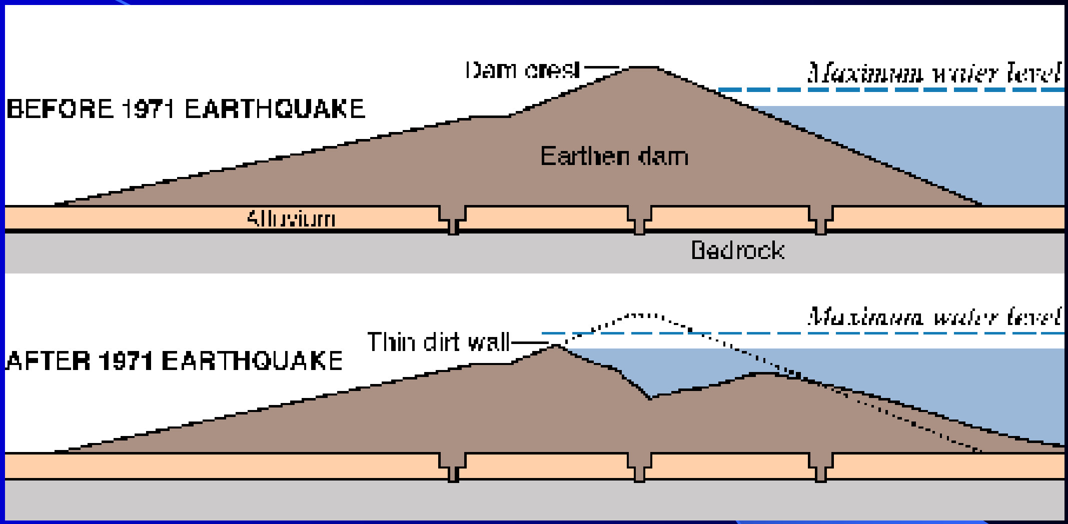
Types of Liquefaction Damage



Lateral Spread

1964 Niigata, Japan Earthquake

Types of Liquefaction Damage



Flow Failure

Lower San Fernando Dam
1971 San Fernando
Earthquake

Valdez, 1964 Alaska
Earthquake

Topics

- Introduction to Liquefaction
- **Performance Base or Risk-Based Ordinances**
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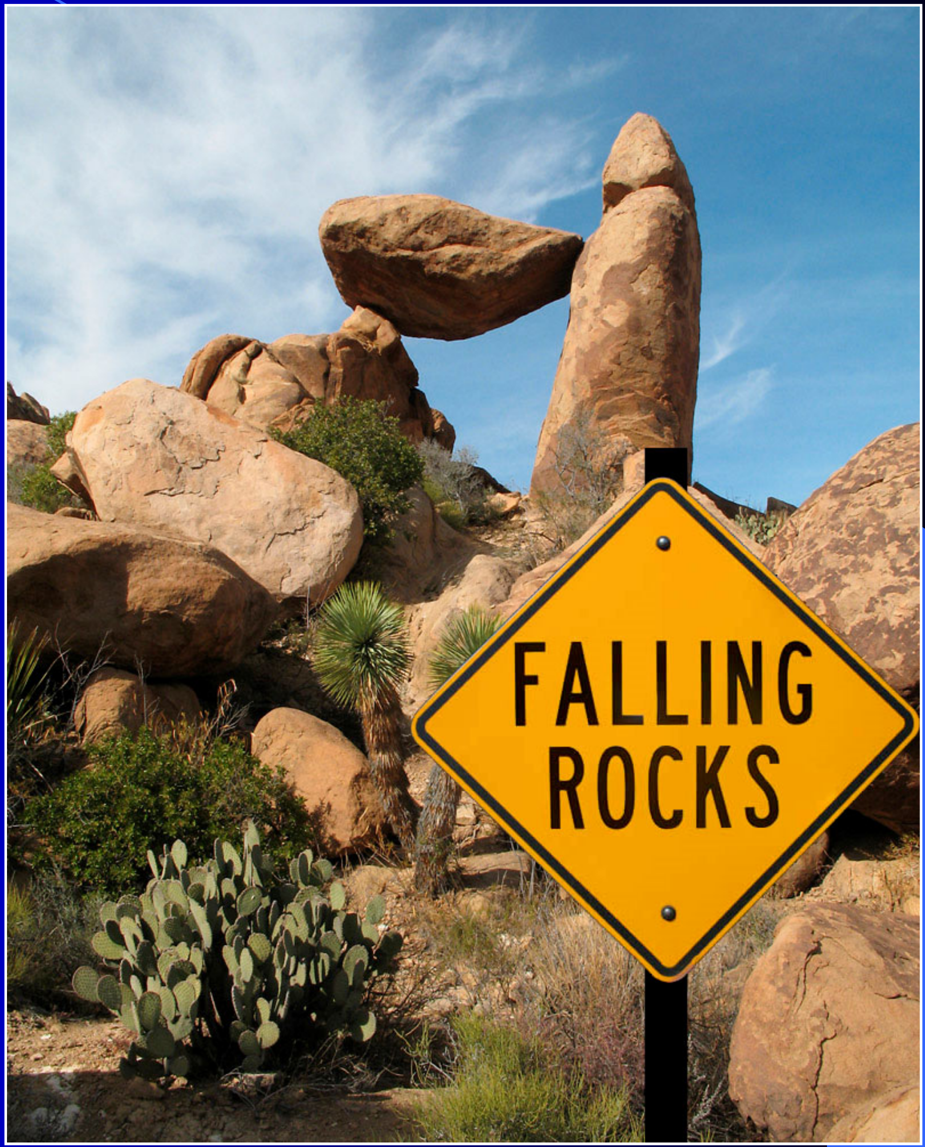
Estimation of Frequency

How often do bad things happen?

Average return period of event (yrs.)?



Estimation of Frequency

Relative Frequency	Frequent	Moderately Frequent	Infrequent	Rare
Frequency of Event[1]	0 to 500 yrs.	500 to 1000 yrs.	1000 to 2500 yrs.	> 2500 yrs.

1 Frequency of event means that the average return period occurs within that time range. For example if a frequency range is between 0 to 500 years, this implies that the event has an average repeat time that falls between 0 and 500 years. The frequency of the event must be established by geological/geotechnical evaluations.

Performance-Based Hazard Ordinances

- **What constitutes "acceptable risk?"**
- **Need a graded, risk-based approach based on performance goals.**

- Level of seismic hazard quantified by frequency or return period of event.
- Facilities/structures/systems classified according to importance.
- Performance goals defined for each class
  - Input owners/stakeholders/public
- Performance goal(s) evaluated in design process.

Classification of Systems

Functional Classification	Examples
Critical (Seismic Use Group III)	Hospitals, fire and police stations, emergency response command and control centers, vital utilities and services.
Essential (Seismic Use Group II)	Essential government and commercial facilities. Multi-unit housing. Important cultural and religious facilities. Facilities containing hazardous or toxic substances. Important bridges and major transportation corridors.
Important (Seismic Use Group I)	Single unit residential housing. Non-essential commercial facilities and utilities. Secondary streets and transportation arteries.
Routine	Non-habitable structures (e.g., garages, sheds, storage facilities, etc.) and private roads.

Safety/Environmental Performance Goals

	Performance Goal
Level 1	No loss of life or injury to occupants. No release of hazardous or toxic substances.
Level 2	No significant loss of life or major injury to occupants or significant release of hazardous or toxic substances.
Level 3	Safety goals are not applicable because these facilities or structures are not used for occupancy.

Systems Performance Goals

	Goal
Level 1 (Operational)	Facility or structure is *functional and operational immediately following the event* without interruption or repair.
Level 2 (Immediate Occupancy)	Facility, structure or system is functional and safe for occupancy soon after the geohazard event without significant loss of function or interruption. Structures should be *safe for occupancy and use within days to a few weeks of the event* with only minor interruption or repair.
Level 3 (Damaged/Repairable)	Facility, structure or system is damaged but repairable following the geohazard event with some interruption. *Structures should be safe for occupancy or use within several months* after the event with major interruption and repair.
Level 4 (Damaged/Irreparable)	Facility, structure or system is severely damaged and is not repairable. *Structures are not safe for occupancy and not repairable; but have not collapsed*.

Performance Goals vs. Event Frequency

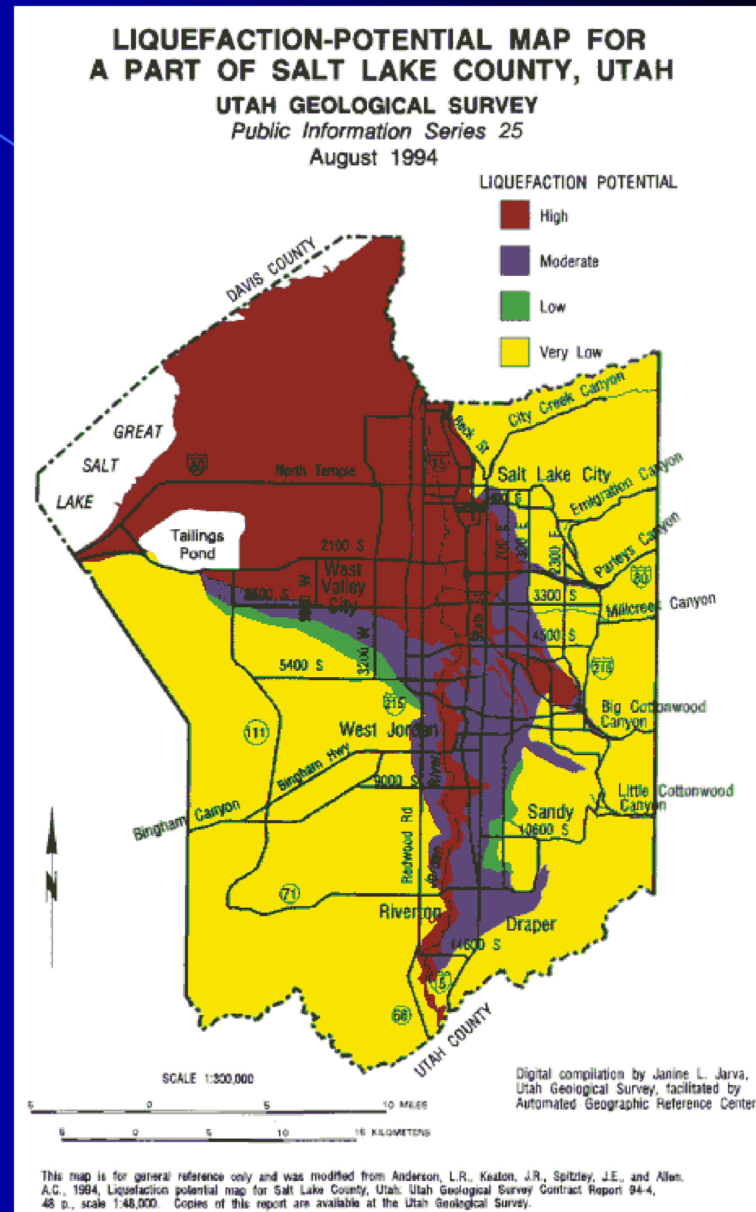
Functional Classification	Frequency of Geohazard	Safety Performance Goal	System Performance Goal
Critical	Frequent Moderately Frequent Infrequent Rare	Level 1 Level 1 Level 1 Level 1	Level 1 Level 1 Level 1 Level 1
Essential	Frequent Moderately Frequent Infrequent Rare	Level 1 Level 1 Level 2 Level 2	Level 1 Level 1 Level 2 Level 3
Important	Frequent Moderately Frequent Infrequent Rare	Level 1 Level 1 Level 2 Level 2	Level 1 Level 1 Level 3 Level 4
Routine	Frequent Moderately Frequent Infrequent Rare	NA NA NA NA	NA NA NA NA

Topics

- Introduction to Liquefaction
- Performance Base or Risk-Based Ordinances
- **Liquefaction Mapping Efforts**
- Modeling of Liquefaction Impacts to Traffic
- Educational Outreach

Previous Liquefaction Maps

- Liquefaction Potential Maps
  - Combine liquefaction susceptibility (capacity) with seismic input (demand).
  - Liquefaction potential for approximate 0.2 g pga
- Improvements
  - No consideration of frequency of event(s)
  - No description or estimate of type of damage



Estimation of Frequency Liquefaction Potential

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

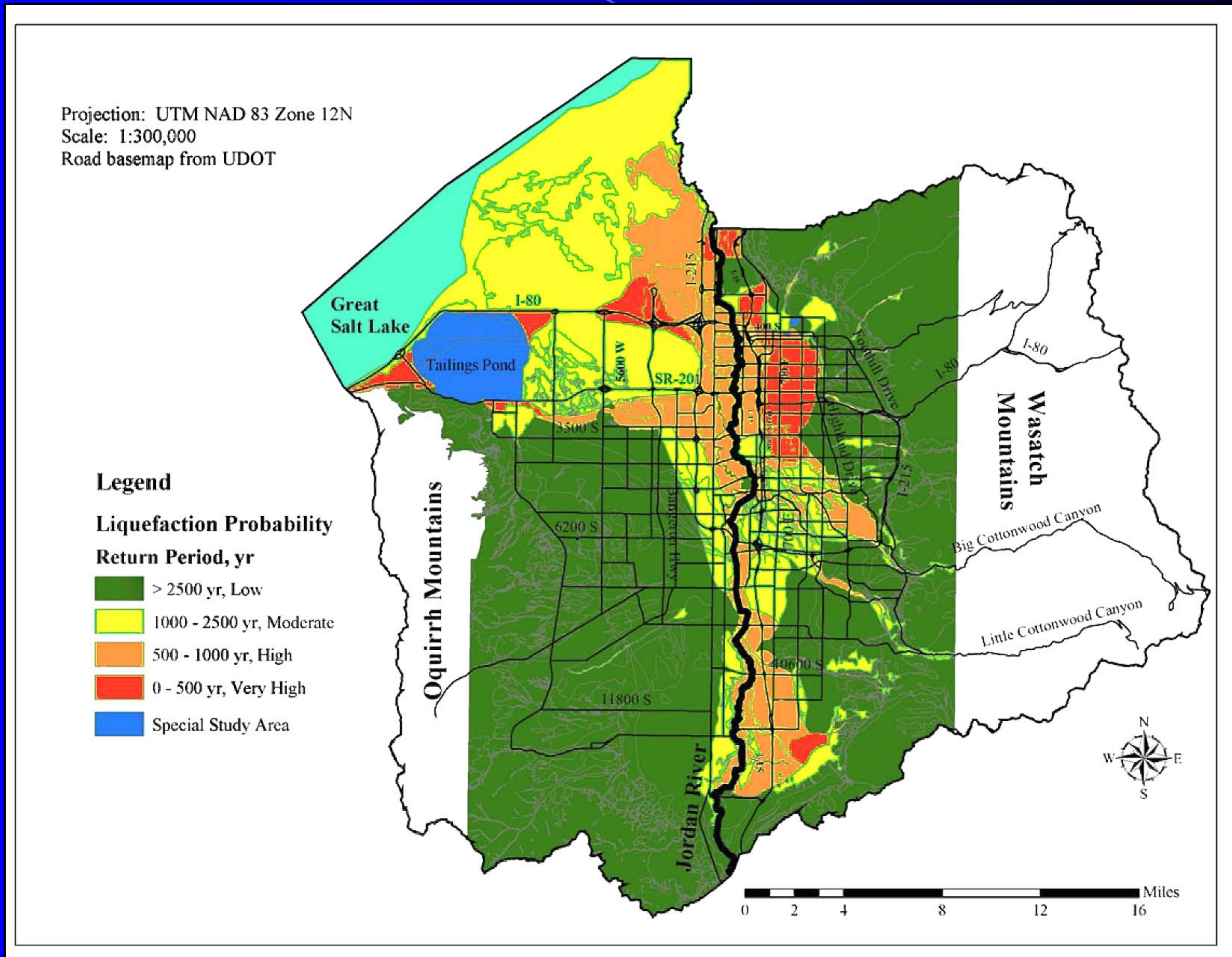
where:

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 Frequency (Liquefaction Return Period)



Estimation of Ground Displacement

- P(DH > x) = Σ 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.

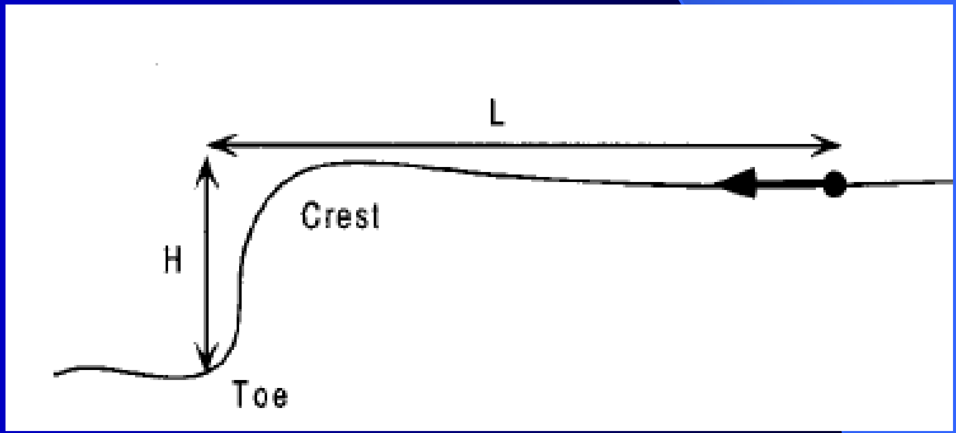
  – P[A,M,R] = joint probability density function of peak ground acceleration, magnitude and source distance.

Estimation of Ground Displacement (Salt Lake Valley)

Youd, Hansen, Bartlett (2002) Empirical Model

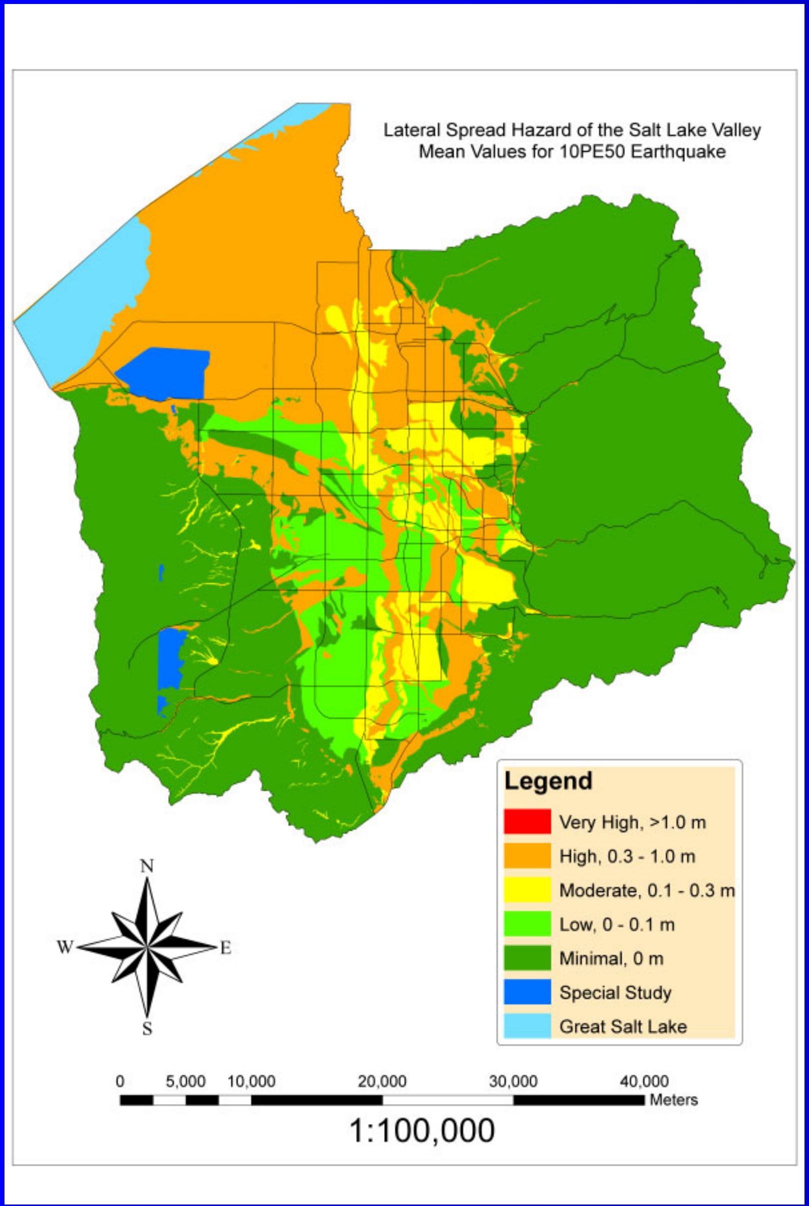
$$LogD_H = \begin{array}{c} b_o + b_{off}\alpha + b_1 M + b_2 LogR^* + b_3 R + b_4 LogW + b_5 LogS + b_6 LogT_{15} + \\ + b_7 Log(100 - F_{15}) + b_8 Log(D50_{15} + 0.1\ \mathrm{mm}) \end{array}$$

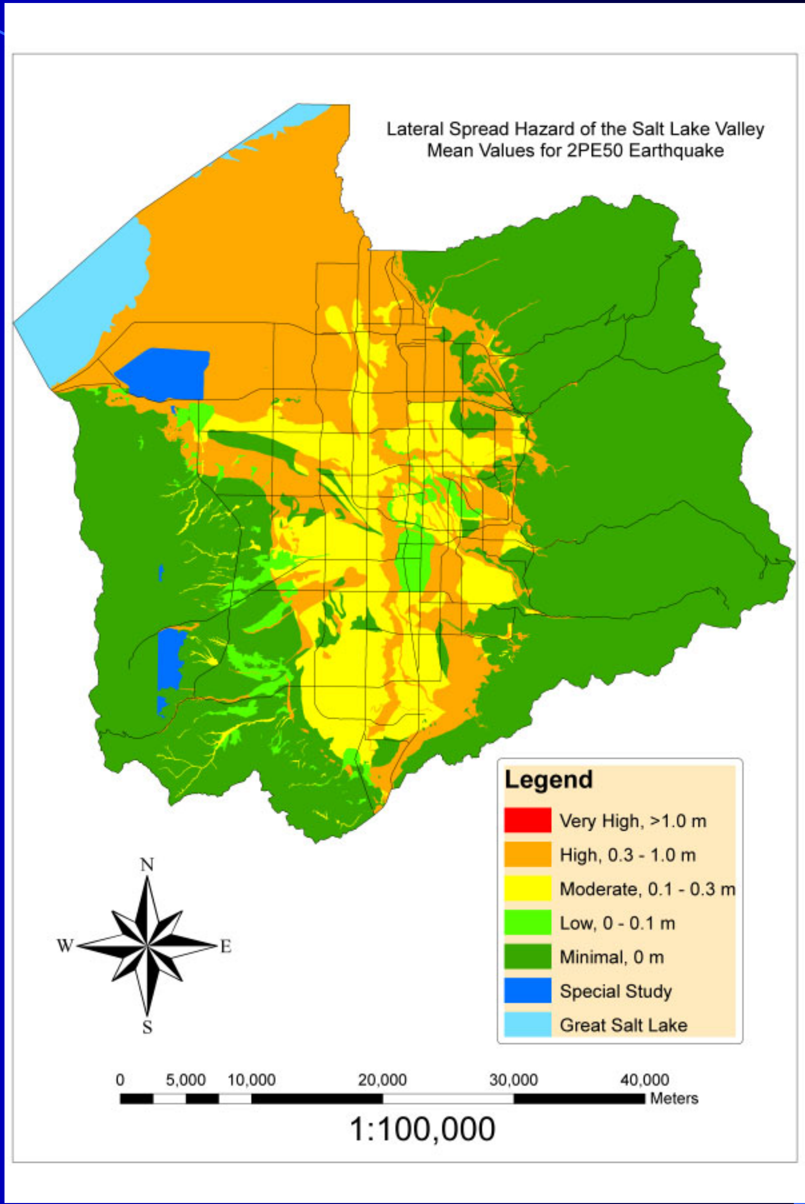
- Seismic Factors
  - *M, R*
- Topographic Factors
  - *W, S*
- Geotechnical Factors
  - T_{15}, F_{15}, $D50_{15}$



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

Ground Displacement (Salt Lake Valley)
Lateral Spread Hazard for 500 and 2500-year periods

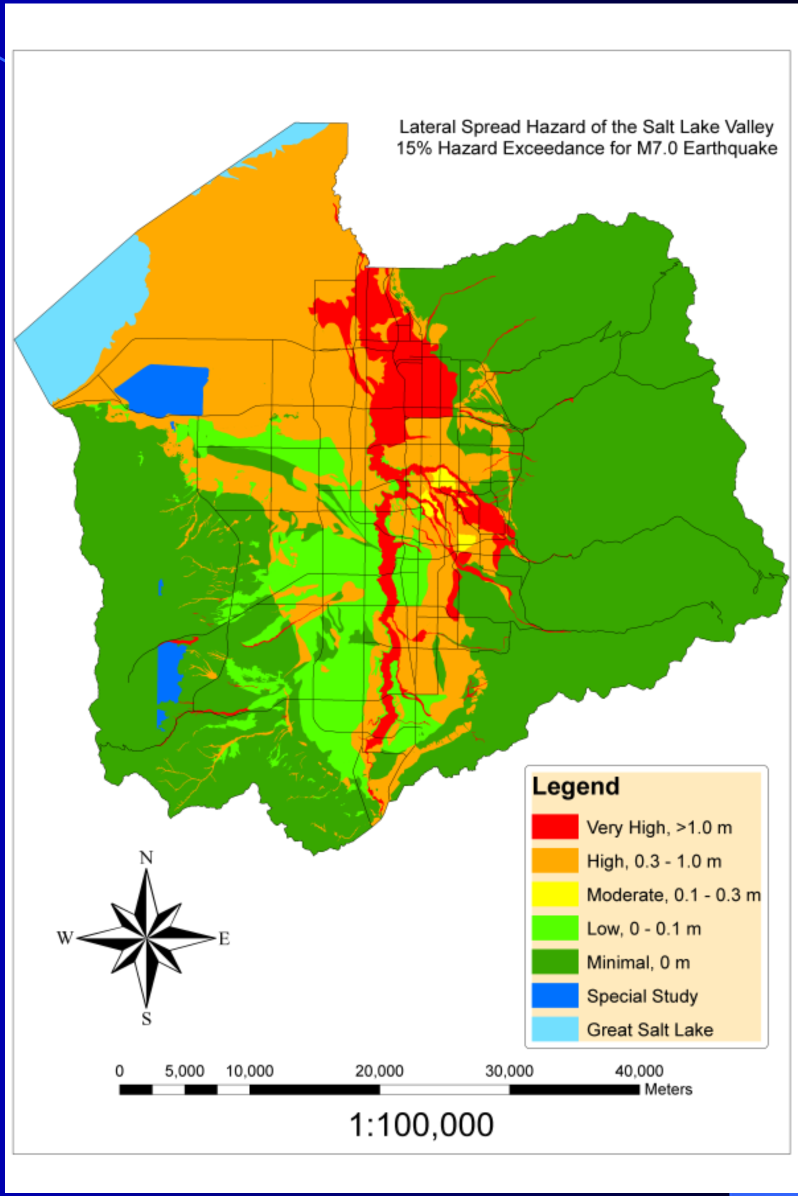




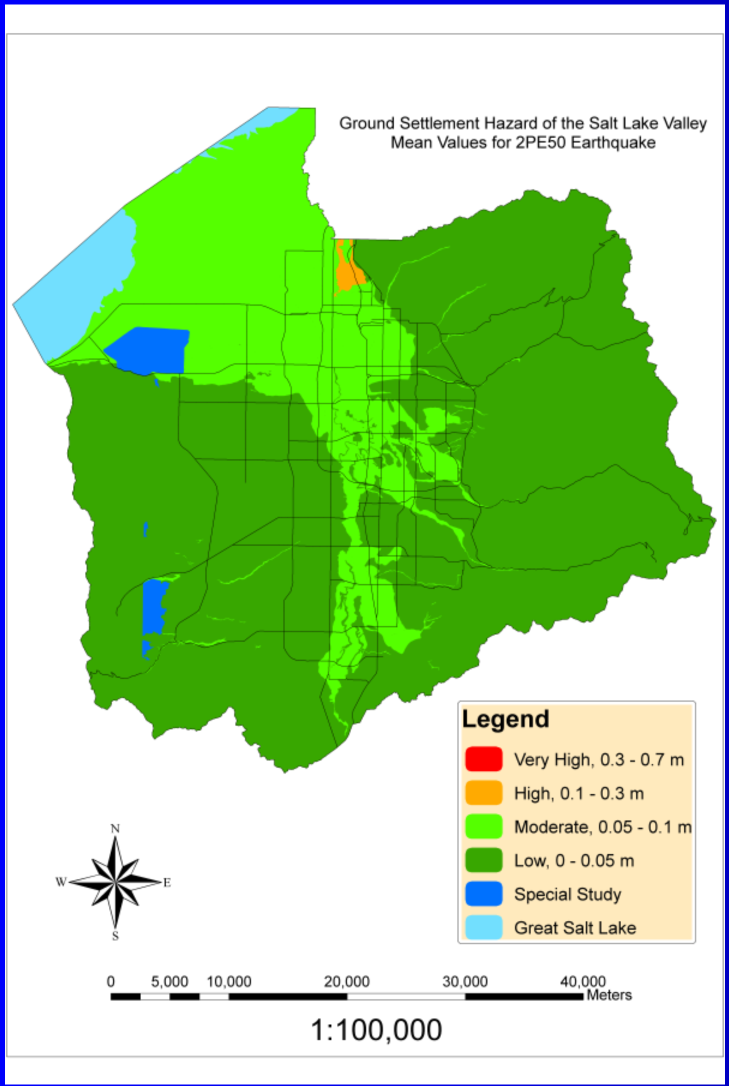
Ground Displacement (Salt Lake Valley)
Lateral Spread or 500 and 2500-year scenarios

M 7.0 Lateral spread displacement map

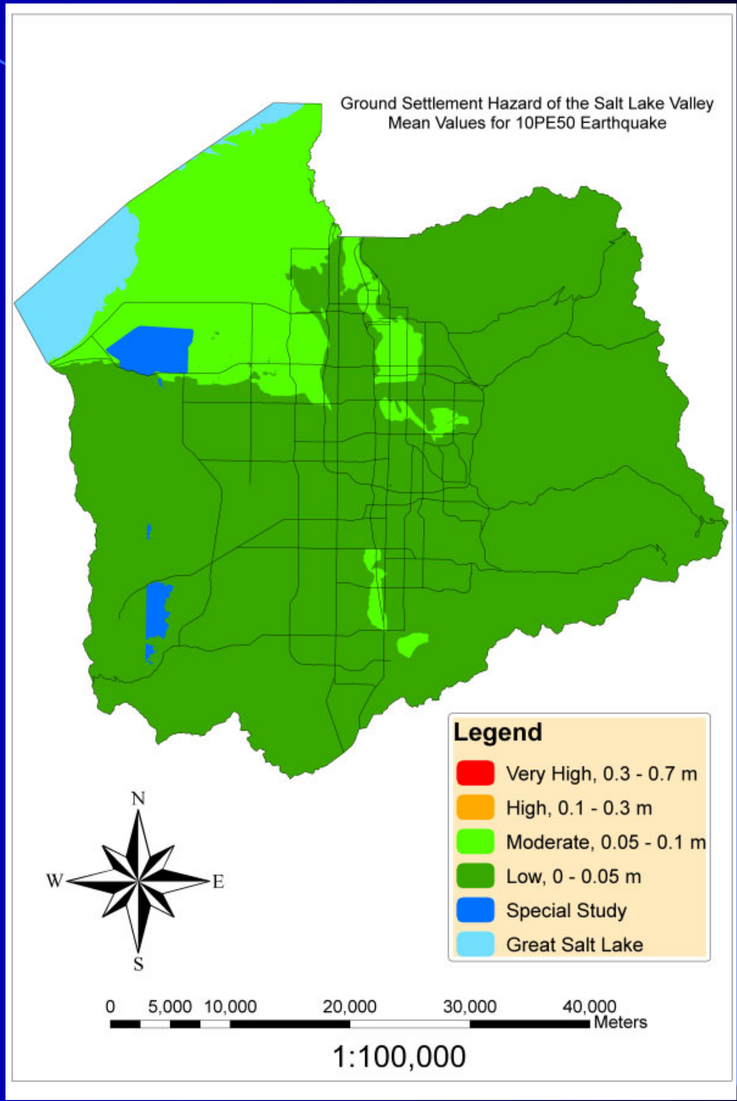
(85 percent chance of non-exceedance)



Settlement (Salt Lake Valley) for 500 and 2500-year scenarios

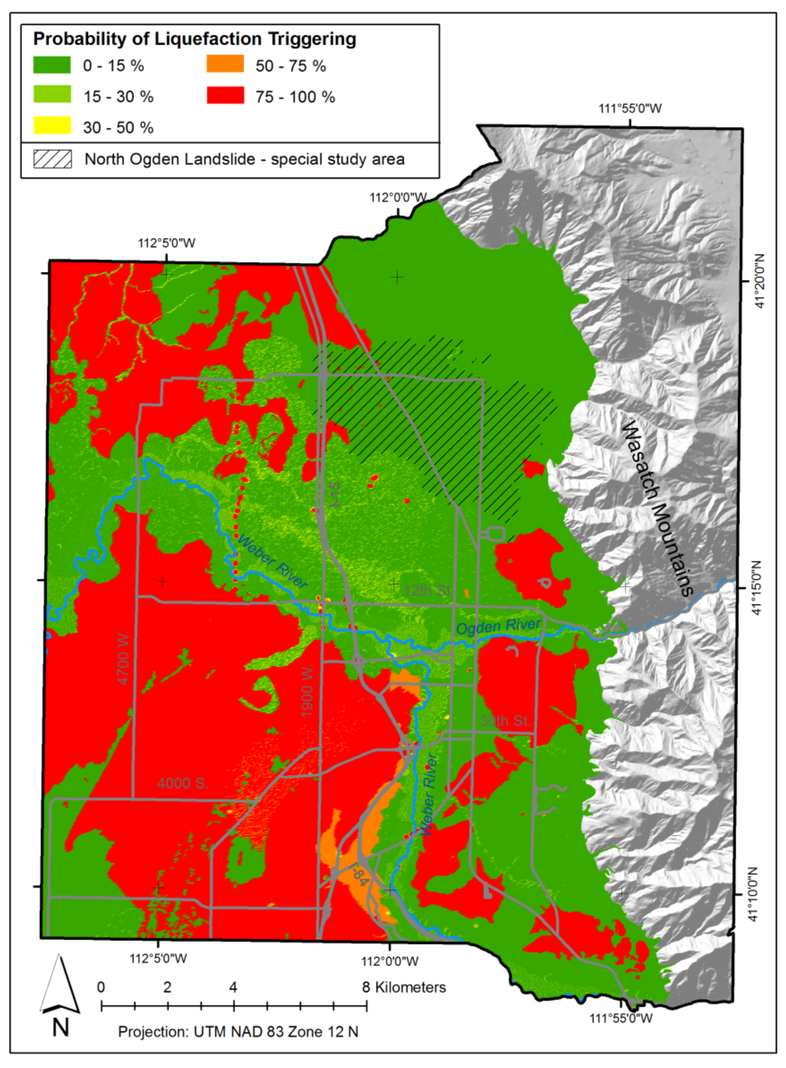


500-yr event

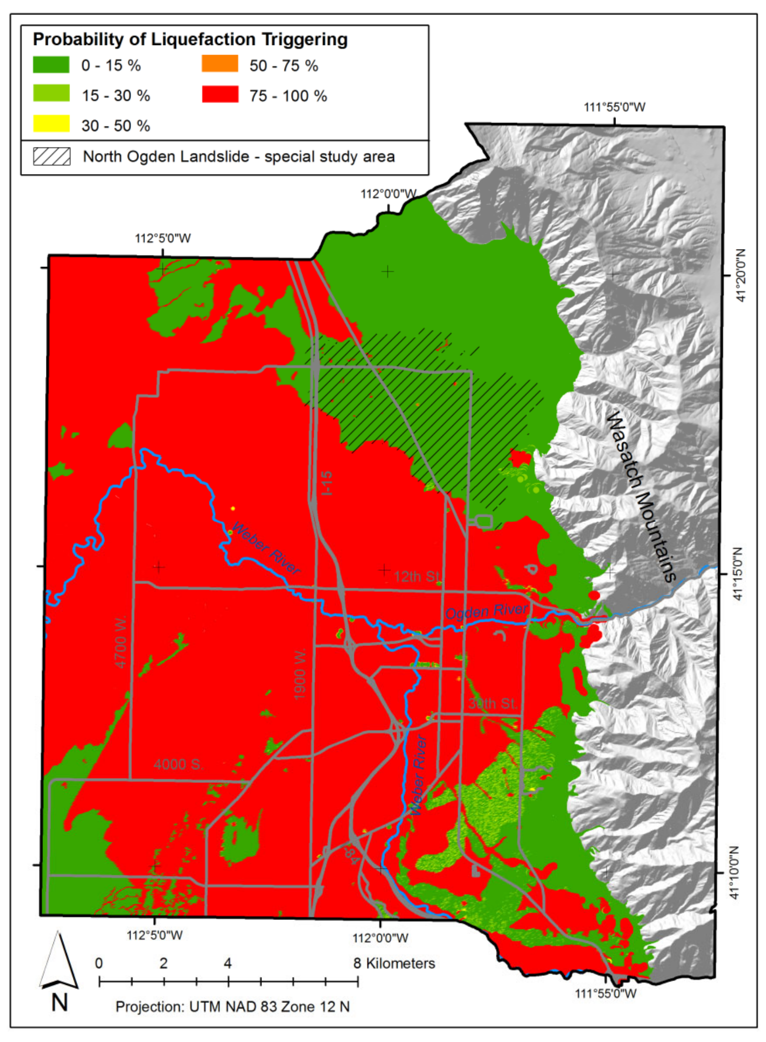


2500-yr event

Liquefaction Potential Maps (Weber County)

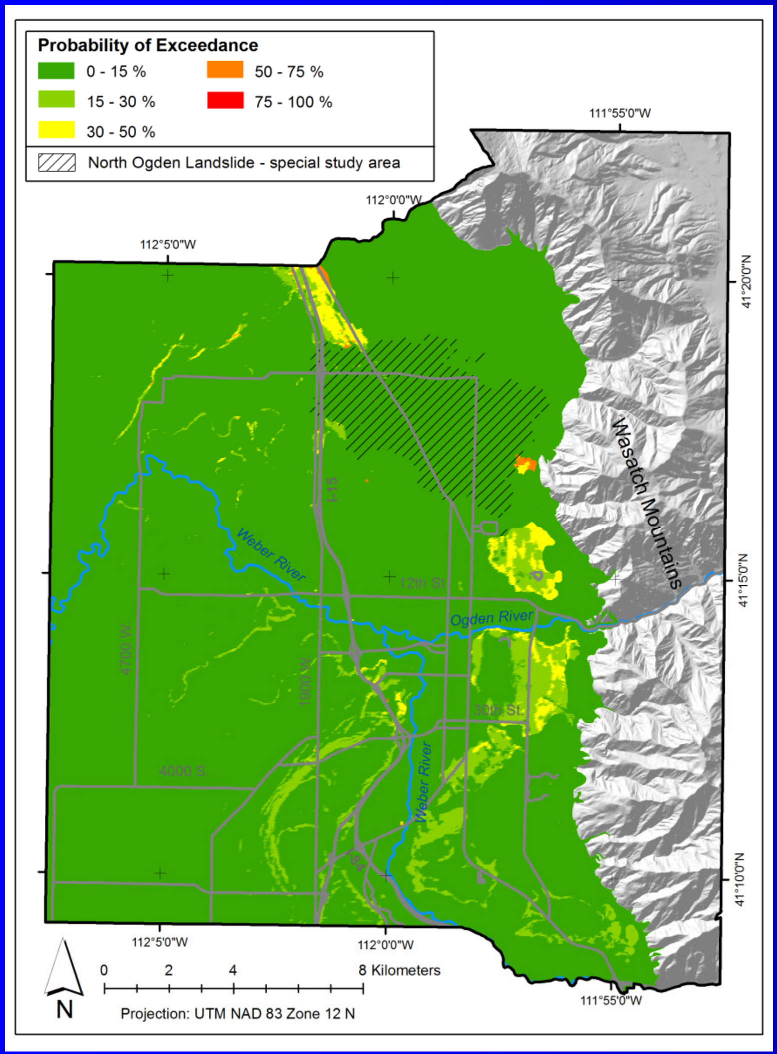


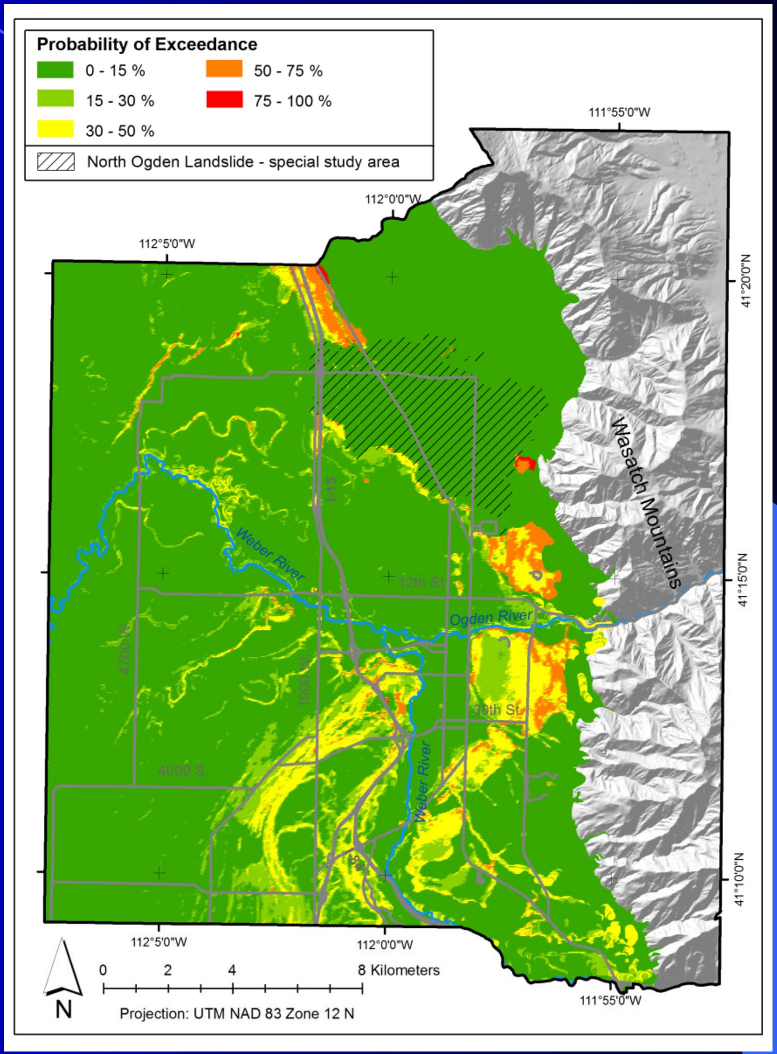
Median probabilities of P_L, 500-year seismic event



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

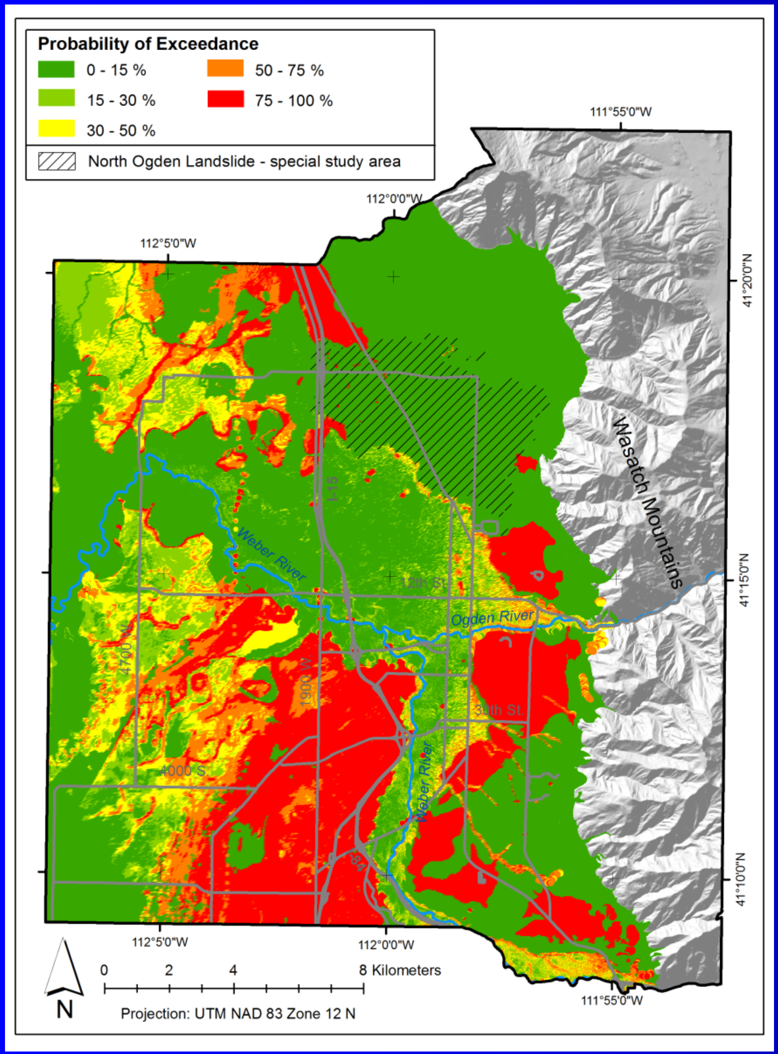
Ground Displacement (Weber Co.)
Lateral Spread for 500 return period



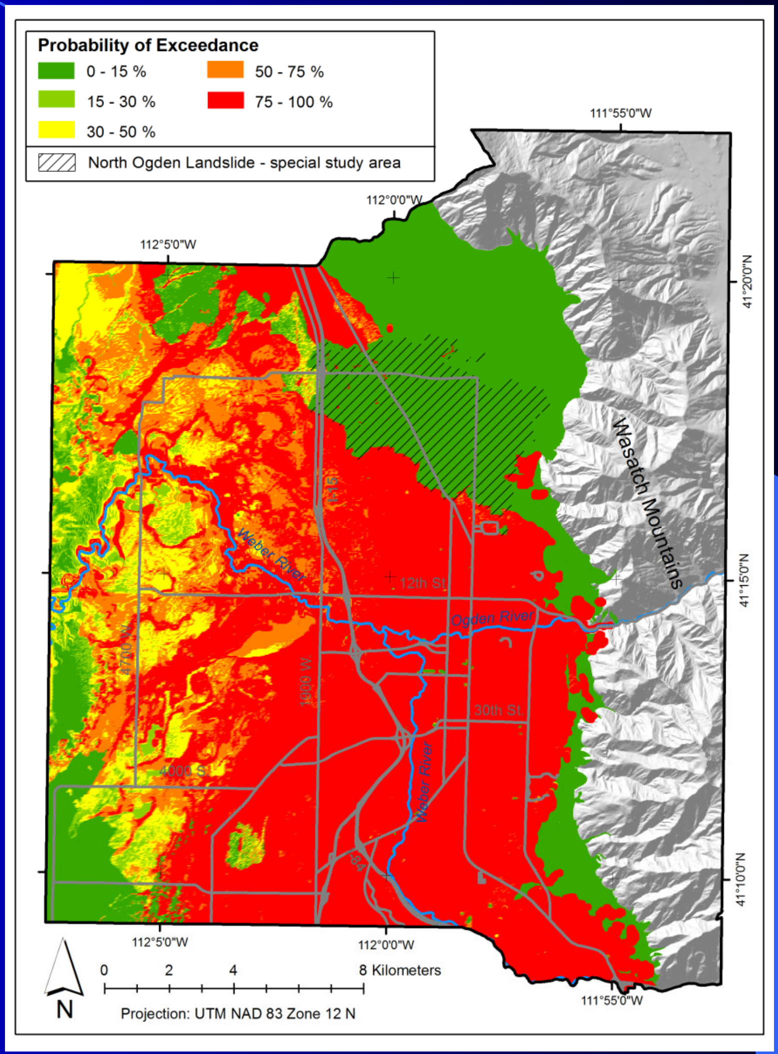


- Median probabilities of exceeding 0.3 m, 500-year event
- 84th percentile probabilities, of exceeding 0.3 m, 500-year event

Ground Displacement (Weber Co.)
Lateral Spread or 2500-year scenario



Median probabilities of exceeding 0.3 m, 2500-year event



84^{th} percentile probabilities, of exceeding 0.3 m, 2500-year event

Mapping Products

the department of
Civil & Environmental Engineering

UNIVERSITY OF UTAH

Utah Liquefaction Advisory Group Webpage

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Topics

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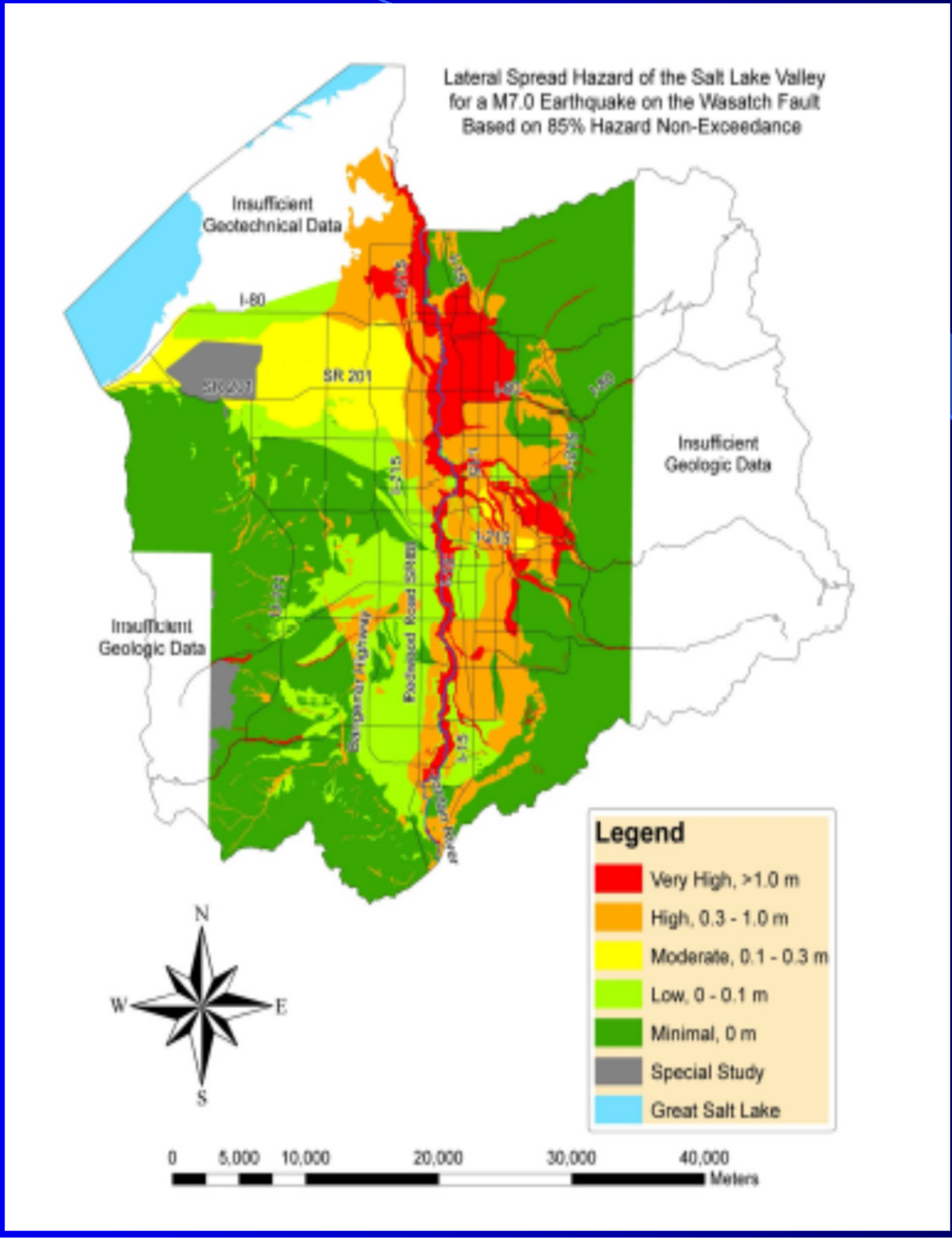
- **Modeling of Liquefaction Impacts to Traffic**
- Educational Outreach

Lateral Spread Hazard Map



Distribution of Lateral Spread Displacement

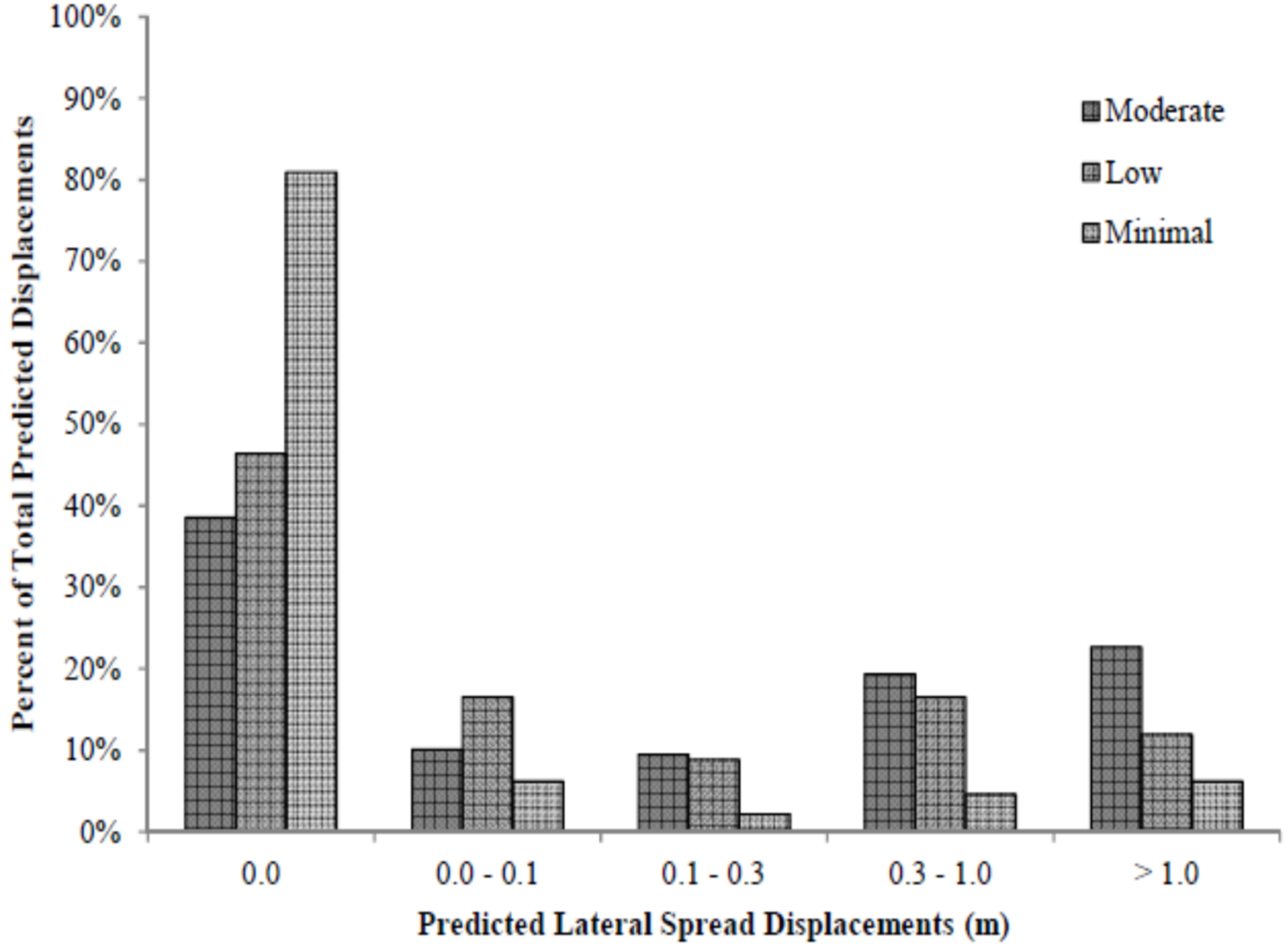


Figure 6: Estimated lateral spread distribution based on PGA associated with 2 percent probability of exceedance in 50 years

Fragility Curves – Relating Displacement to Damage

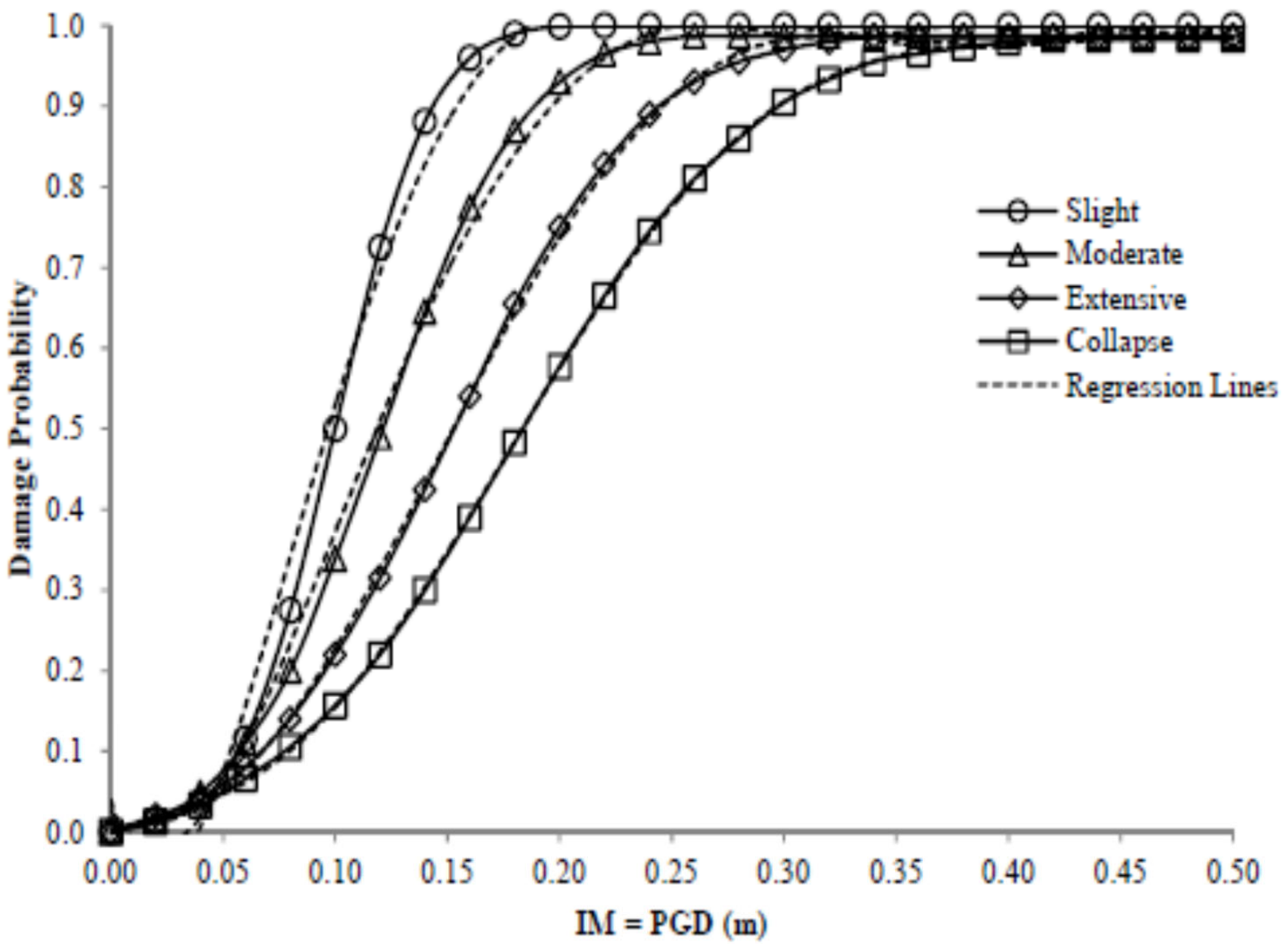


Figure 18: Polynomial fit fragility curves for bridges with integral abutments (Brandenberg, Zhang, Kashighandi, Huo, & Zhao, 2011)

Probability of Damage State for Various Hazard Areas for M=7.0 Earthquake

Table 4: Mean and standard deviation values representing the probability of falling within any given damage state due to a M7.0 seismic event

Structure Type	Lateral Spread Hazard Area	Probability of Falling within Damage State									
		None		Slight		Moderate		Extensive		Collapse	
		μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Bridge with Integral Abutments	Very High	0.459	0.478	0.021	0.042	0.015	0.043	0.012	0.034	0.491	0.473
	High	0.622	0.461	0.025	0.044	0.024	0.057	0.022	0.050	0.307	0.416
	Moderate	0.758	0.387	0.028	0.049	0.021	0.052	0.016	0.040	0.178	0.338
	Low	0.892	0.280	0.014	0.013	0.002	0.011	0.002	0.011	0.091	0.273
	Minimal	0.934	0.214	0.013	0.001	0.000	0.001	0.000	0.000	0.053	0.214

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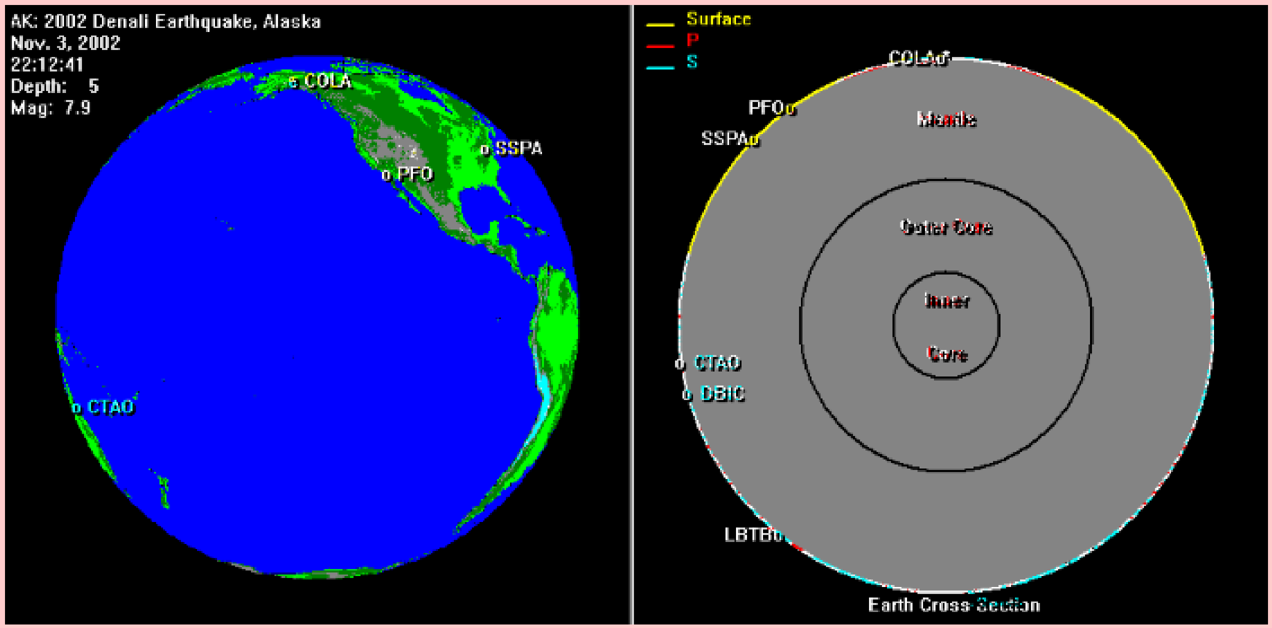
Educational Outreach
Earthquake Mobile Lab

Educational Outreach

INTRODUCTION TO EARTHQUAKE HAZARDS



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Educational Outreach