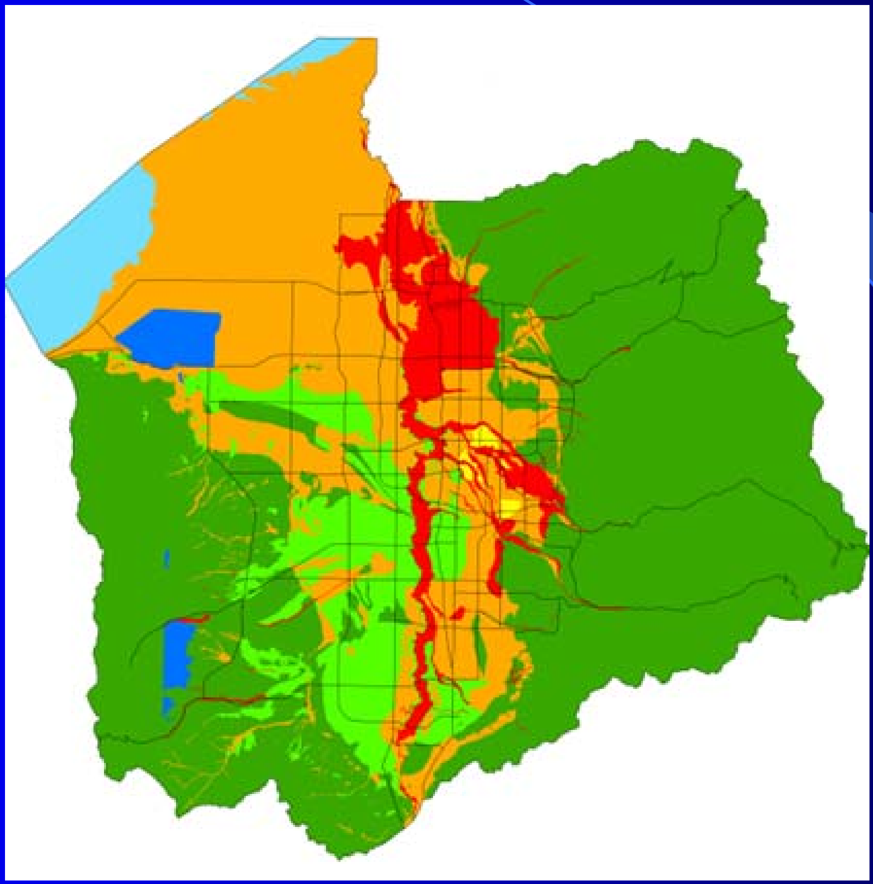
Liquefaction Hazards – From Mapping to Implementation



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

ULAG 2015
Salt Lake City, Utah

THE UNIVERSITY OF UTAH

Utah Liquefaction Advisory Group

__Members__

Steve Bartlett, UU CE, Facilitator

Mike Hylland, UGS liaison

Mark Petersen, USGS liaison

Les Youd, BYU CE

Travis Gerber, BYU CE

Kyle Rollins, BYU CE

Loren Anderson, USU CEE

Jim Bay, USU CEE

John Rice, USU CEE

Aurelian Trandafir, UU G&G

Michael Olsen, UCSD

David Simon, SBI

Grant Gummow, UDOT

Jim Higbee, UDOT

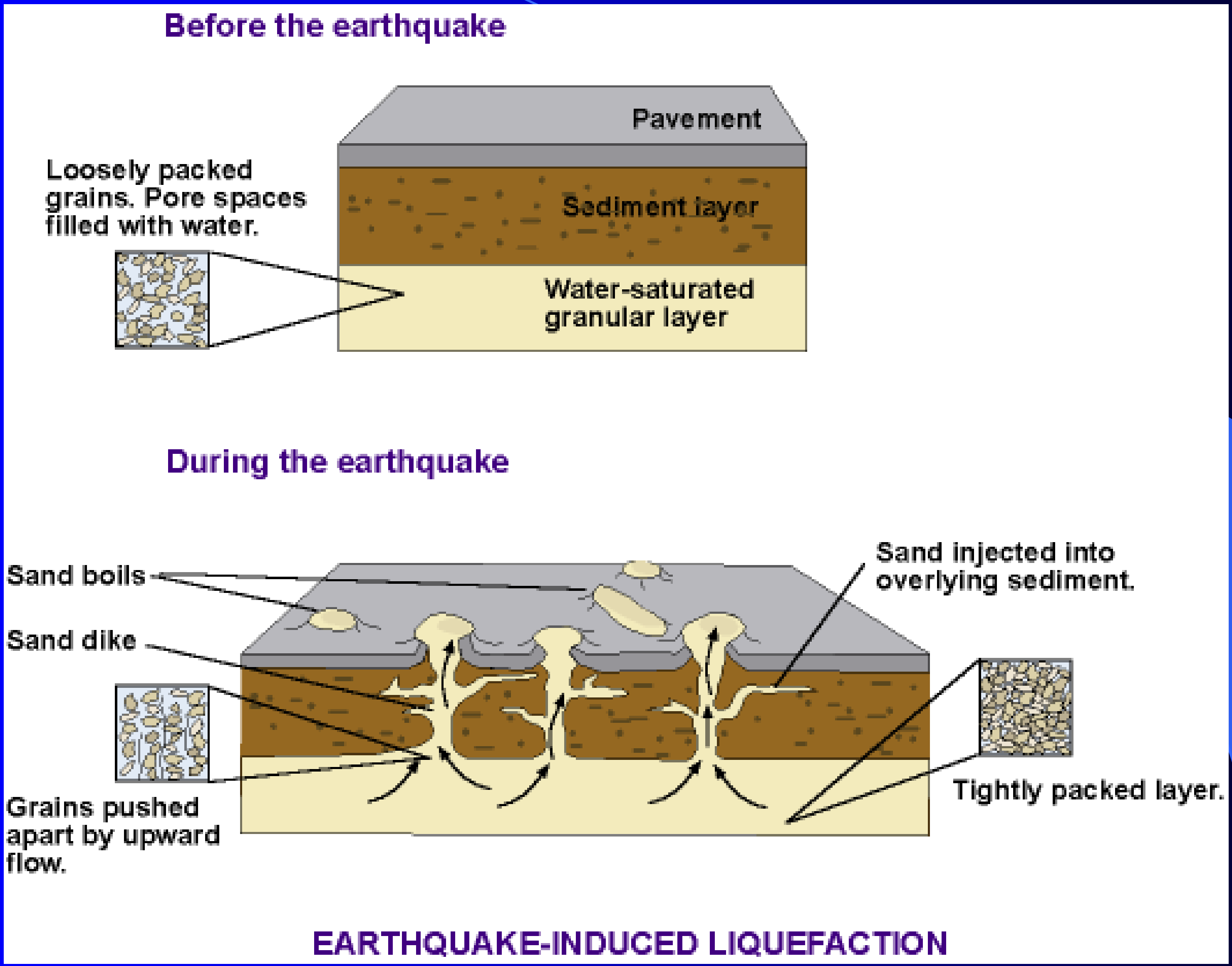
Bill Turner, Earthtec

Ryan Cole, Gerhart-Cole

Topics

- Liquefaction Damage
- Types of Liquefaction Maps
- Estimation of Frequency
- Estimation of Liquefaction Potential
- Estimation of Ground Displacement
- Estimation of Settlement
- Performance-Based Hazard Ordinances

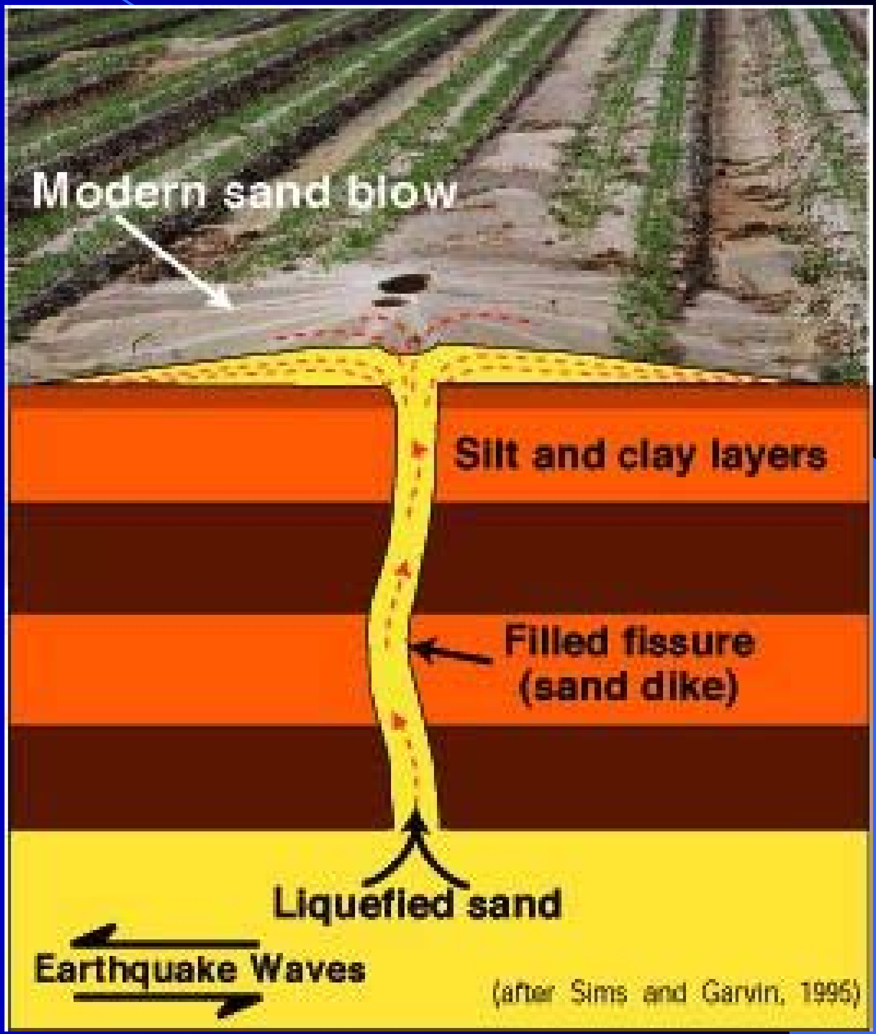
Liquefaction



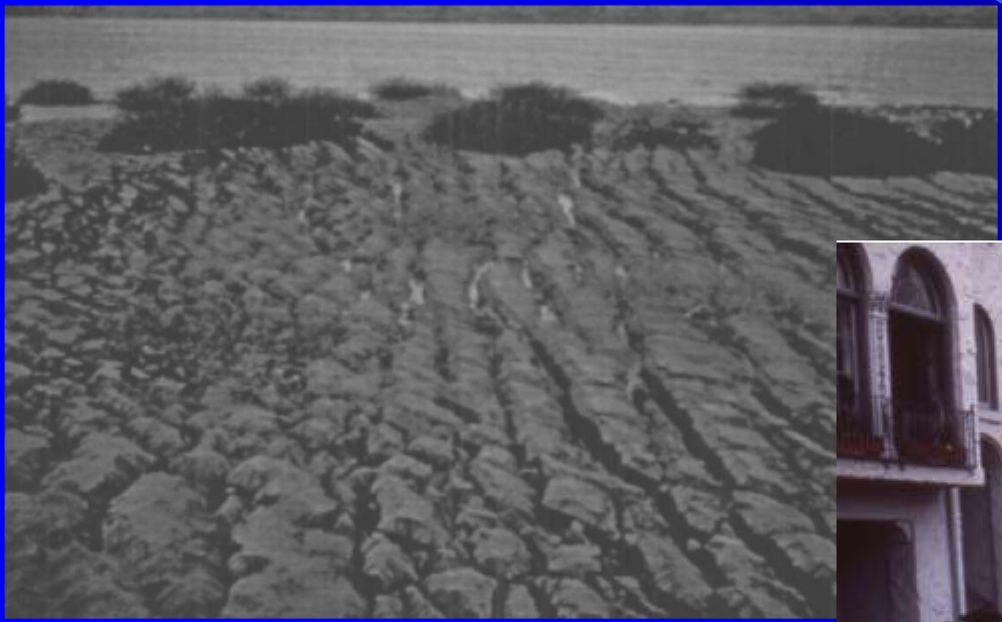
What is liquefaction?

Types of Liquefaction Damage

Sand Blow or Sand Volcano



Types of Liquefaction Damage



Ground Oscillation

Marina District, San Francisco,
1989 Loma Prieta Earthquake

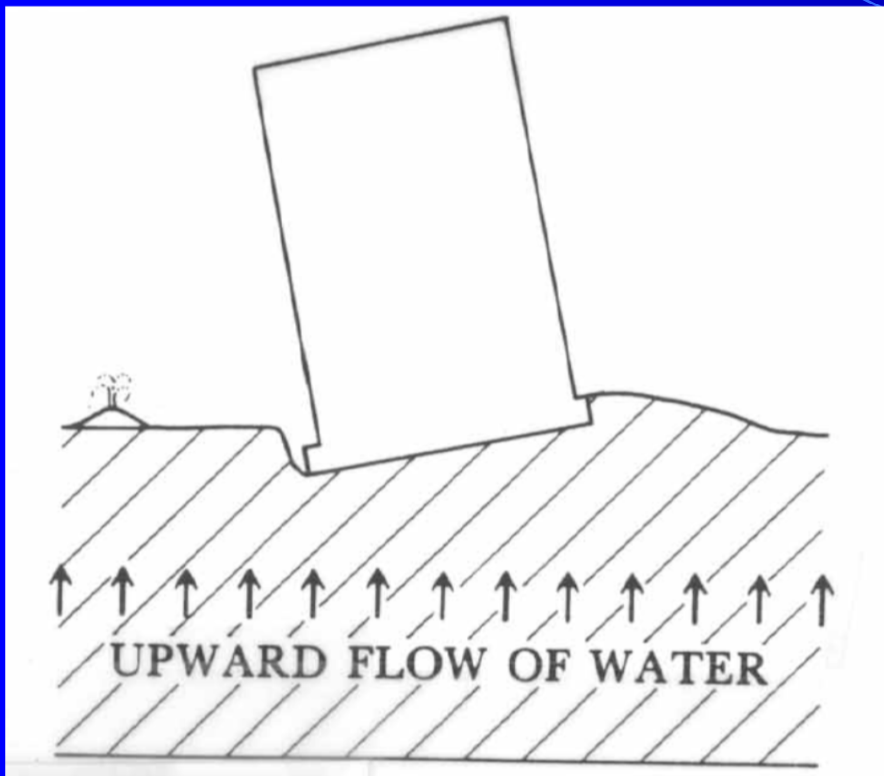
Types of Liquefaction Damage

2011 Tohoku Earthquake

Ground Settlement

2010 Christchurch Earthquake

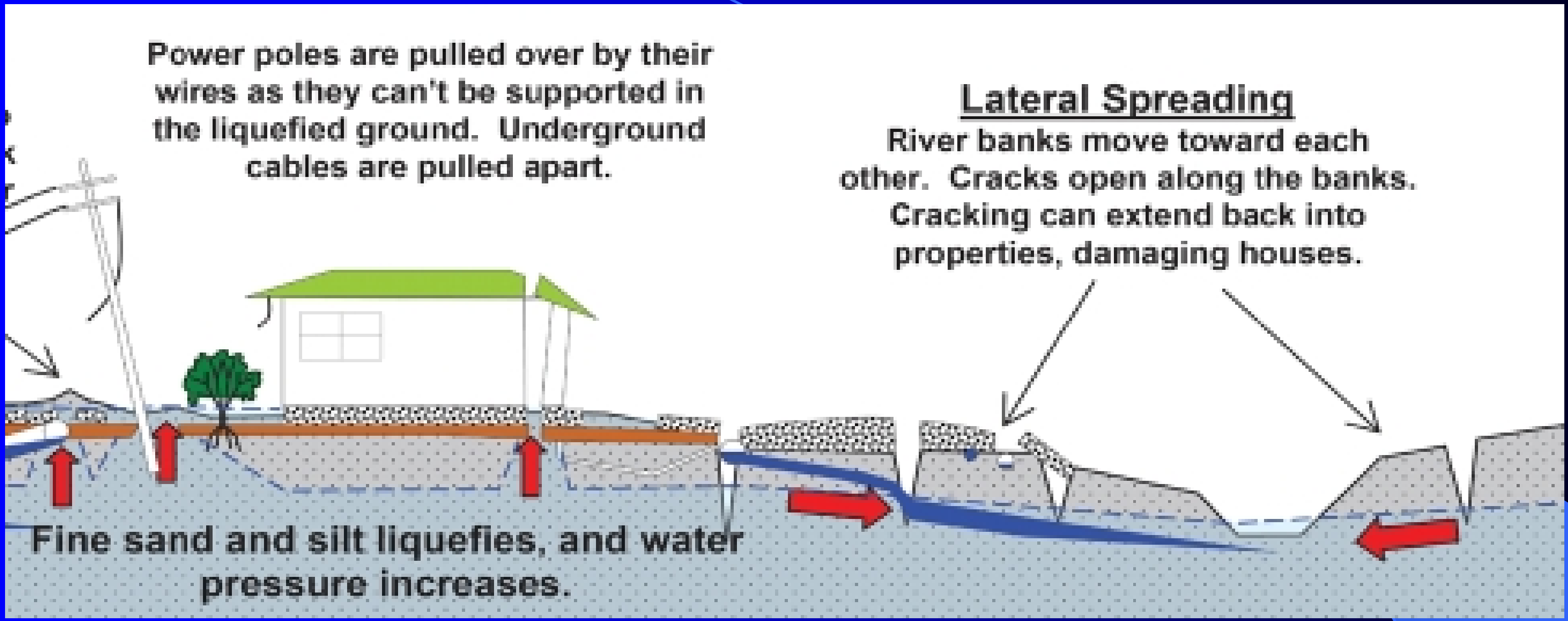
Types of Liquefaction Damage



Bearing Capacity Failure

1964 Niigata, Japan Earthquake

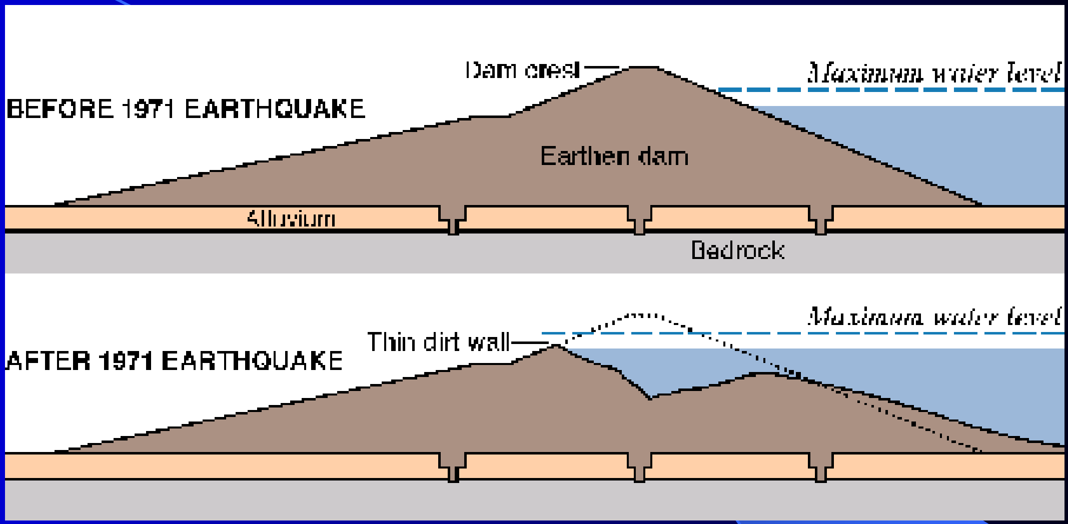
Types of Liquefaction Damage



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

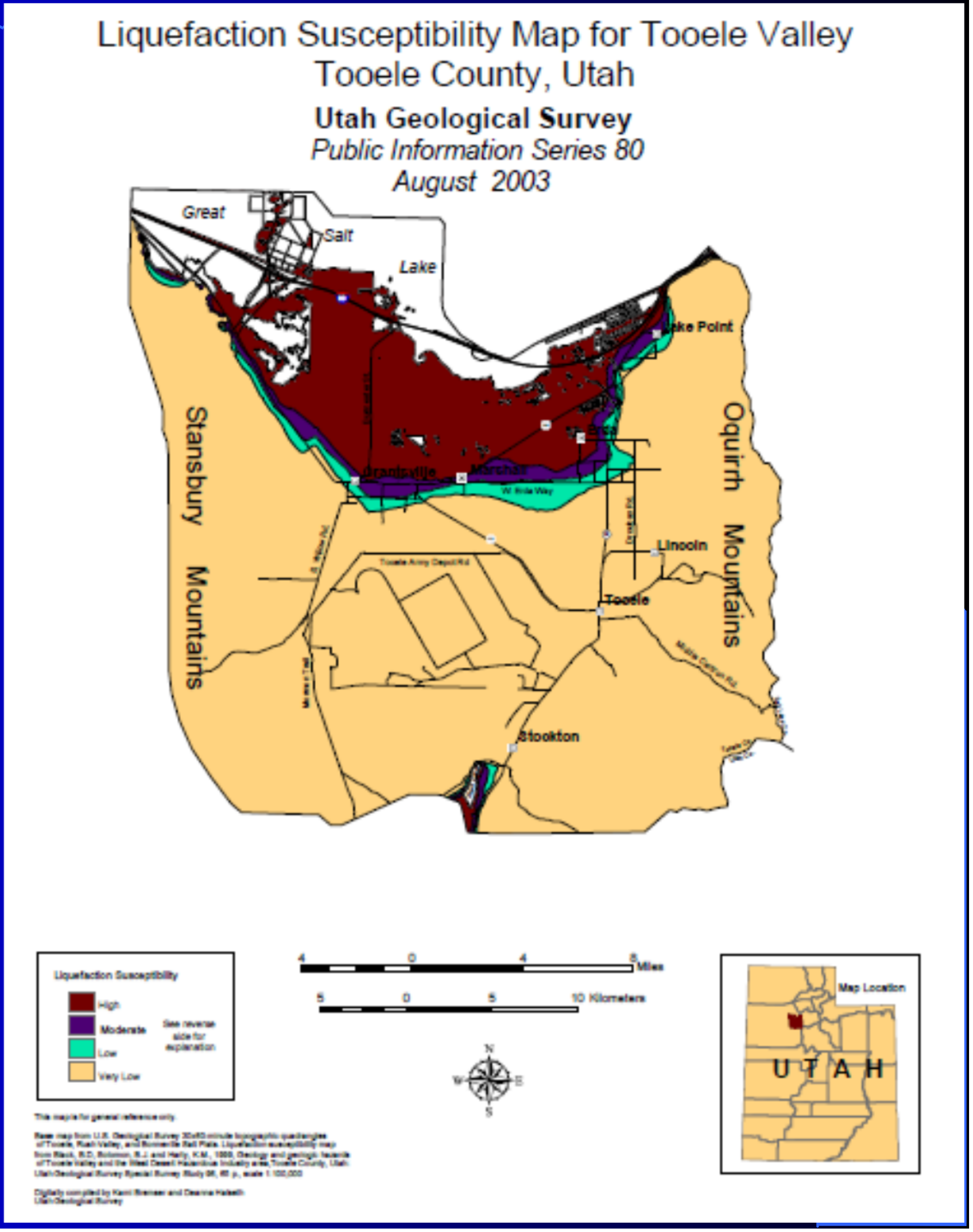
- Liquefaction Damage
- **Types of Liquefaction Maps**
- Estimation of Frequency
- Estimation of Liquefaction Potential
- Estimation of Ground Displacement
- Estimation of Settlement
- Performance-Based Hazard Ordinances

Types of Liquefaction Maps

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

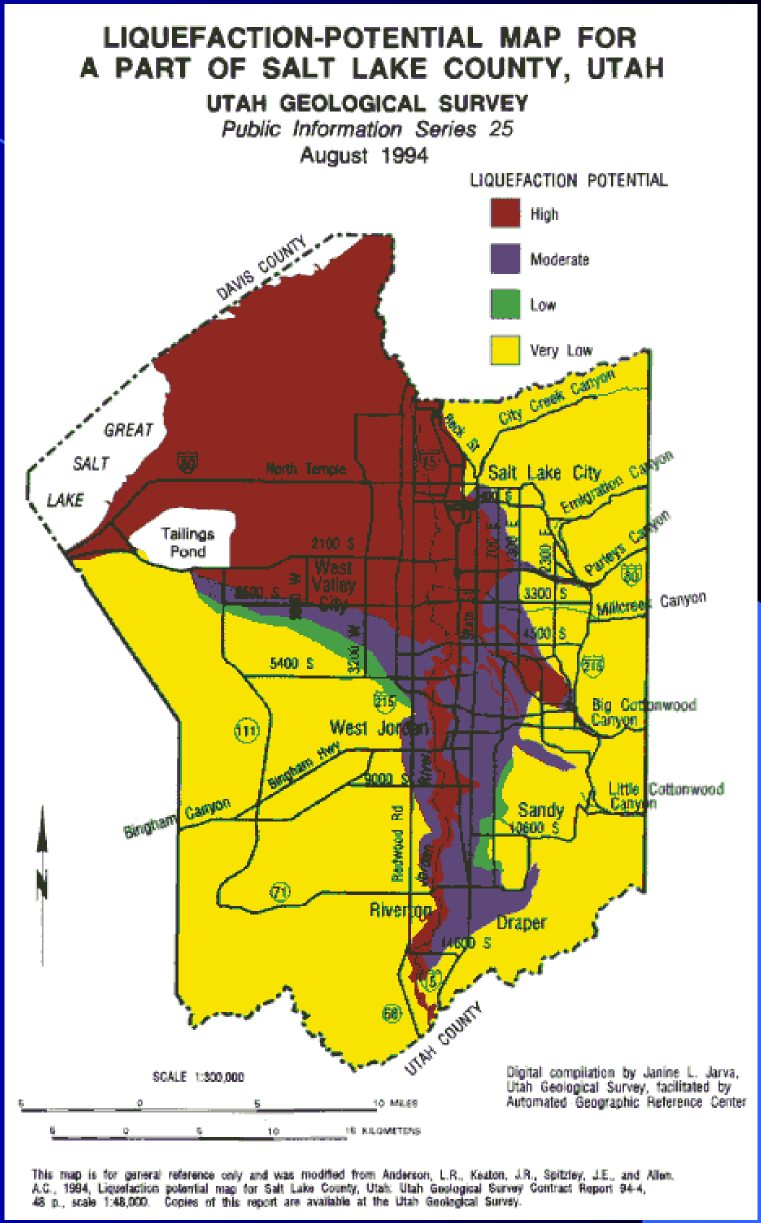
Types of Liquefaction Maps

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



Types of Liquefaction Maps

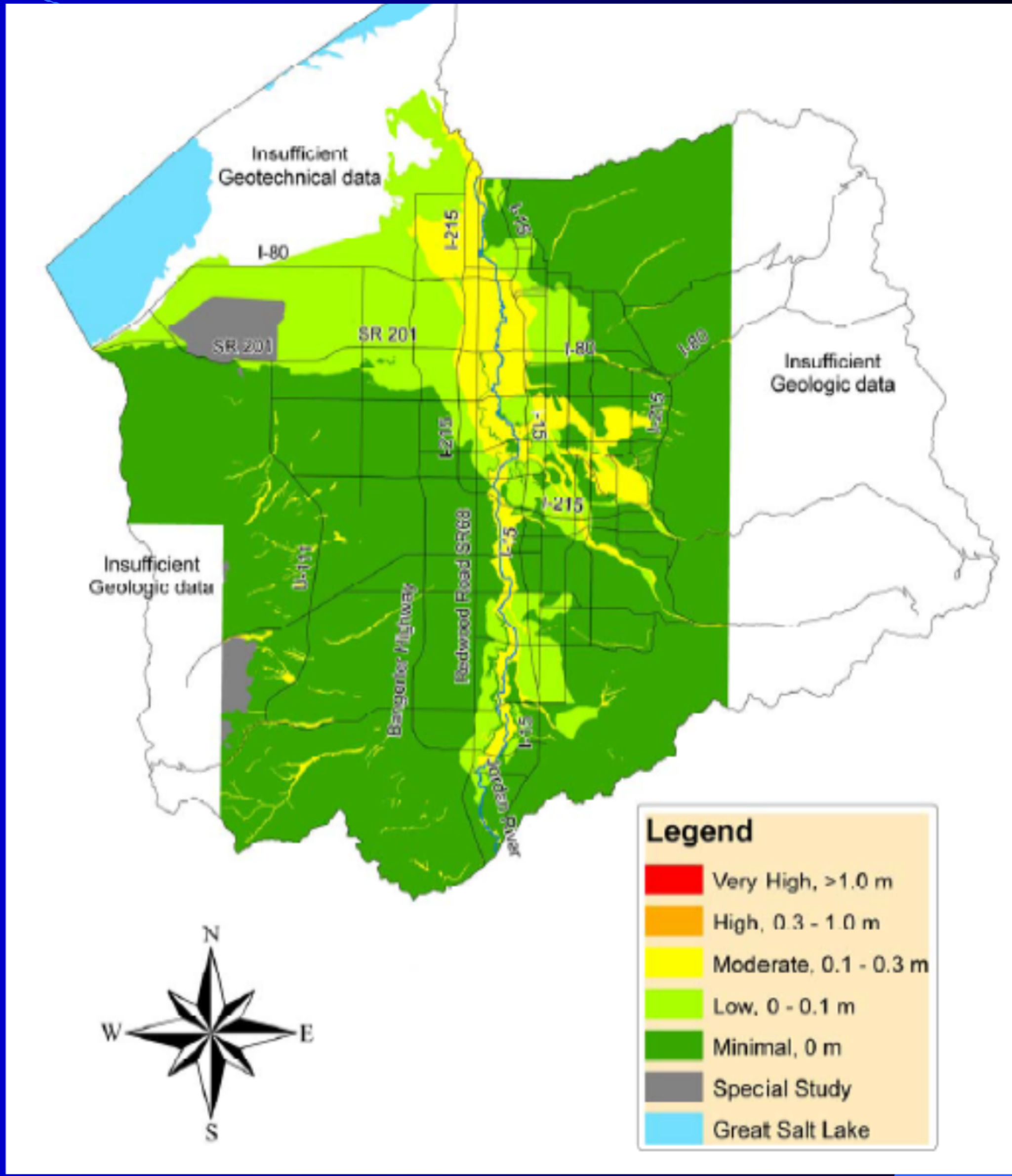
- Liquefaction Potential Maps
  - Combine liquefaction susceptibility (capacity) with seismic input (demand).
  - Demand can be expressed as a deterministic scenario event or a probabilistic-based estimate obtained from the national seismic hazard maps



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 for 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
- Lateral Spread maps (using above scenarios)
- Ground settlement maps (using above scenarios)
- Fully aggregated liquefaction map with PSHA input
    - (see next two slides)

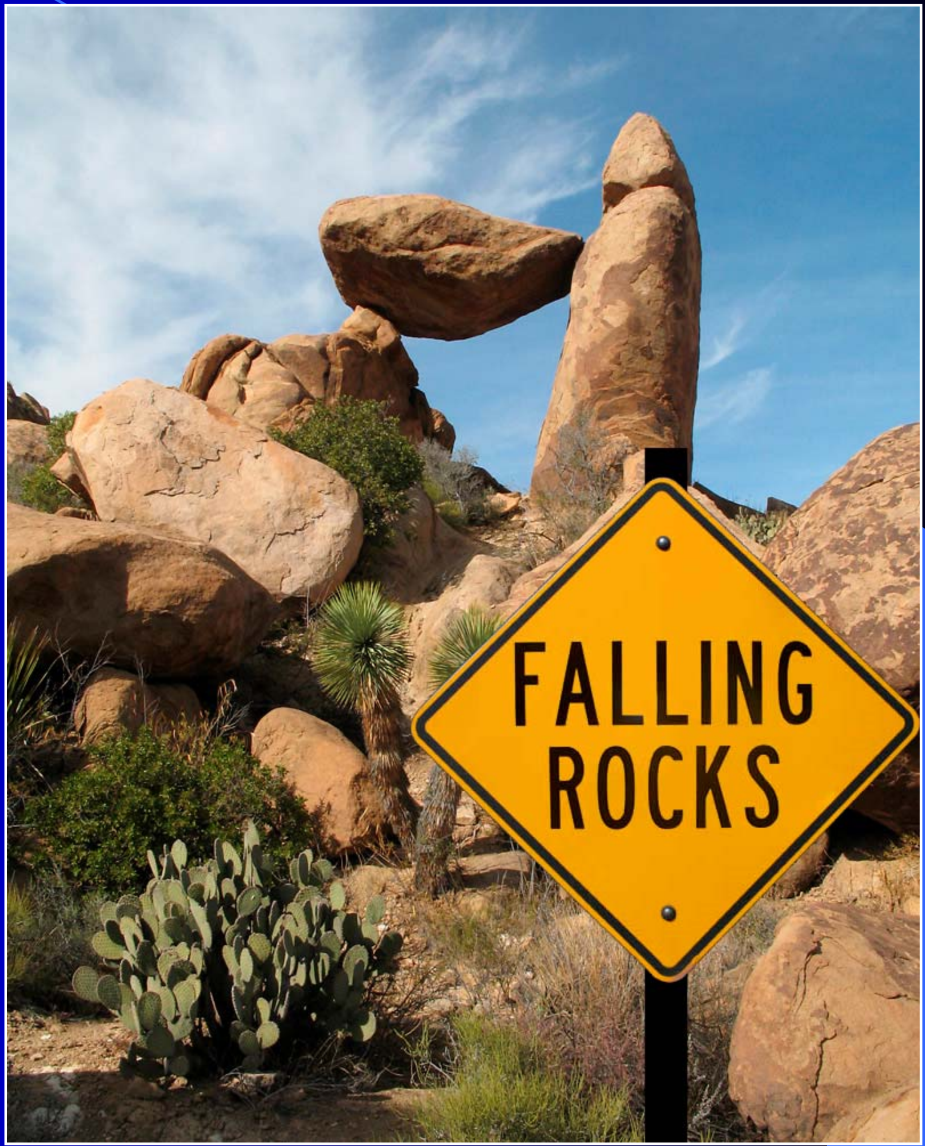
Topics

- Liquefaction Damage
- Types of Liquefaction Maps
- **Estimation of Frequency**
- Estimation of Liquefaction Potential
- Estimation of Ground Displacement
- Estimation of Settlement
- Performance-Based Hazard Ordinances

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.

Topics

- Liquefaction Damage
- Types of Liquefaction Maps
- Estimation of Frequency
- **Estimation of Liquefaction Potential**
- Estimation of Ground Displacement
- Estimation of Settlement
- Performance-Based Hazard Ordinances

Estimation of Frequency Liquefaction Potential

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

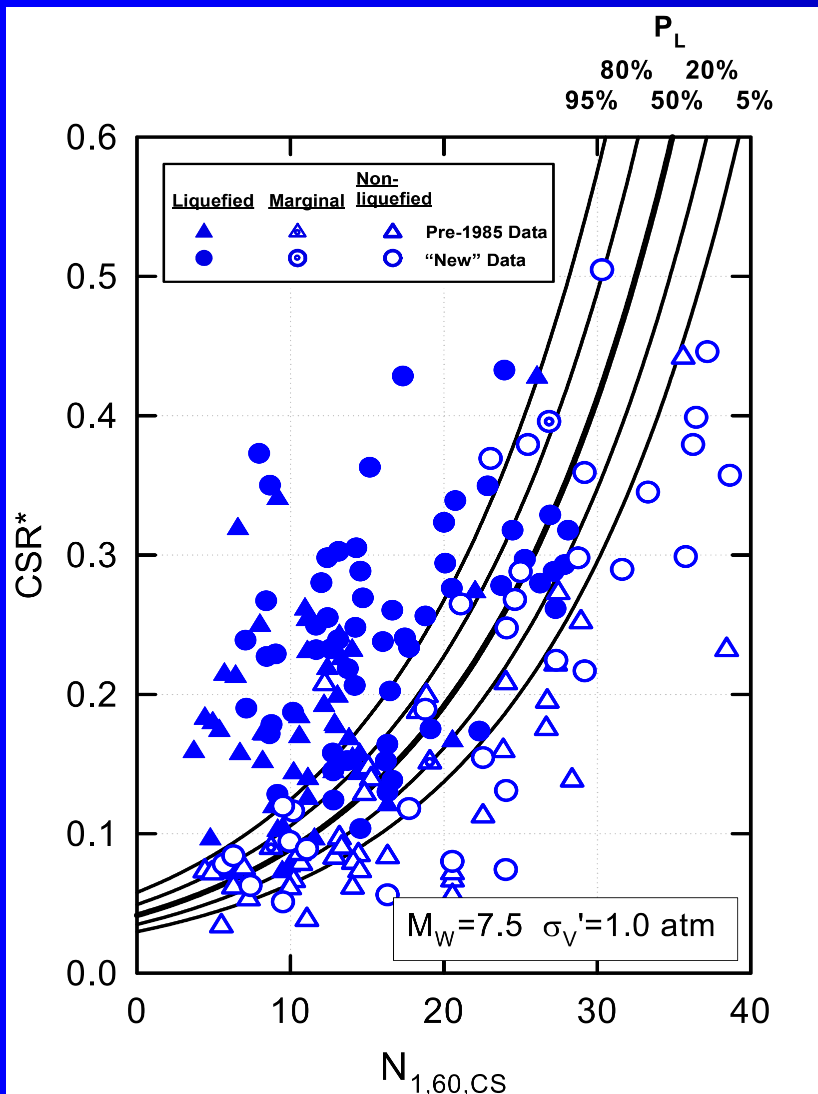
where:

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 Potential



Recommended "Probabilistic" SPT-Based Liquefaction Triggering Correlation

(For MW=7.5 and σv'=1.0 atm)

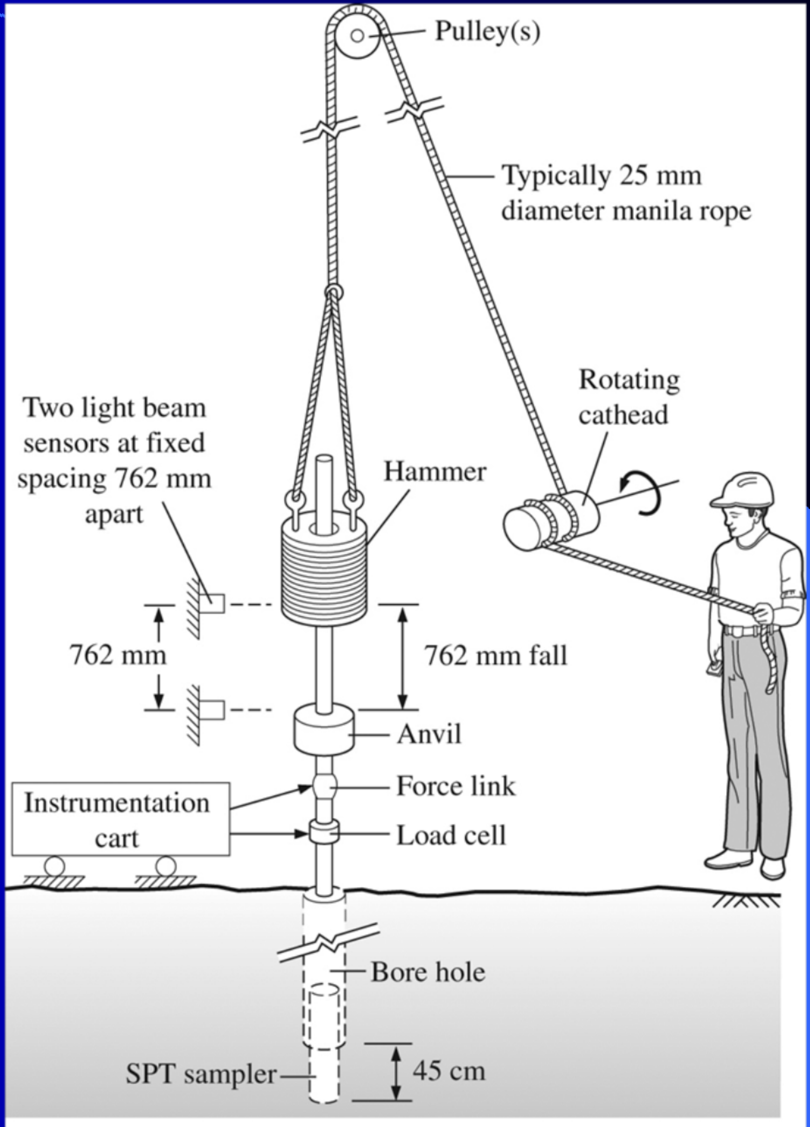
(Seed et al. 2003)

Estimation of Frequency Liquefaction Potential

- Subsurface data collection
  - Standard Penetration Testing (SPT)
  - Cone Penetrometer Testing (CPT)

Estimation of Frequency Liquefaction Potential

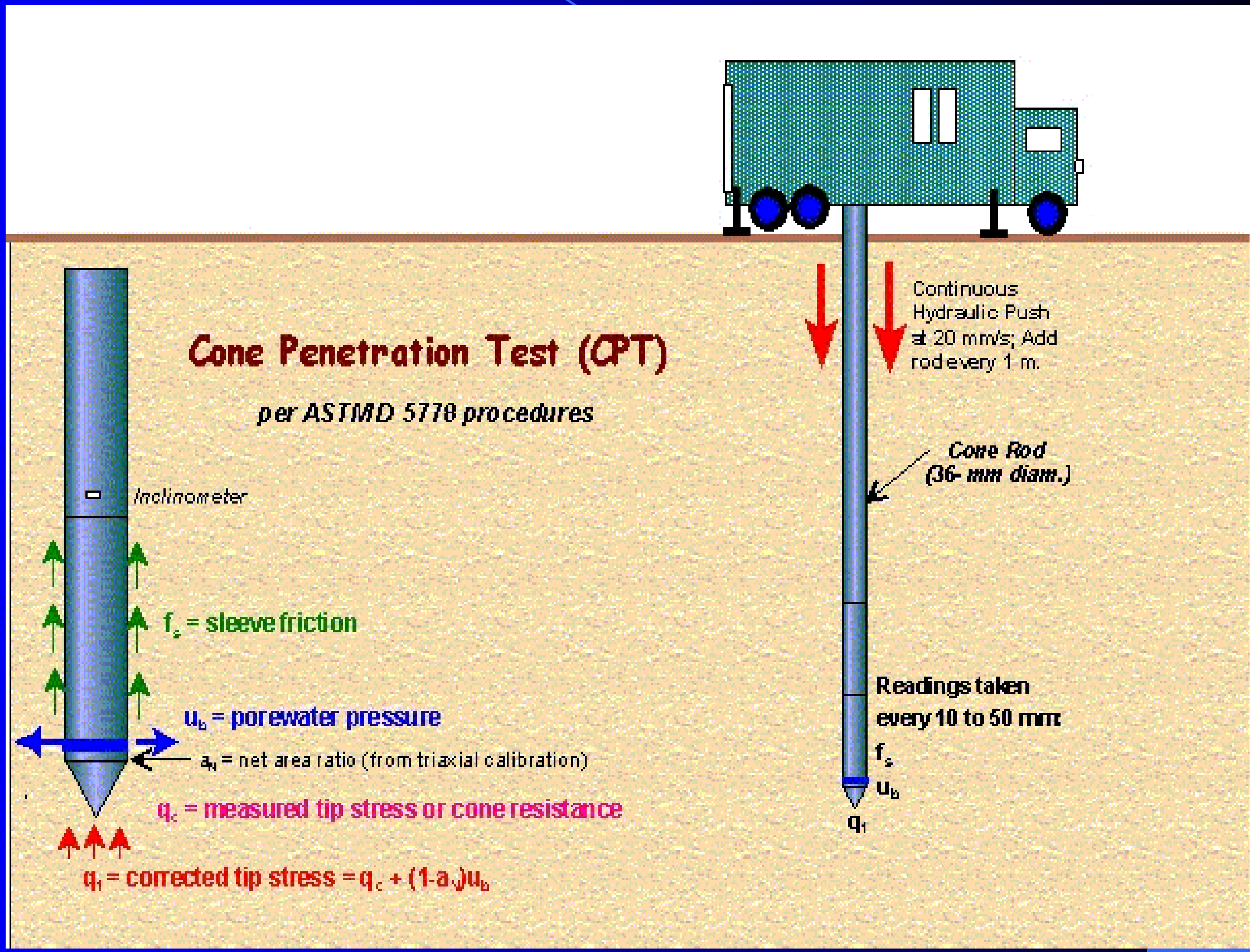
- Subsurface data collection
  - Standard Penetration Testing (SPT)



(a)

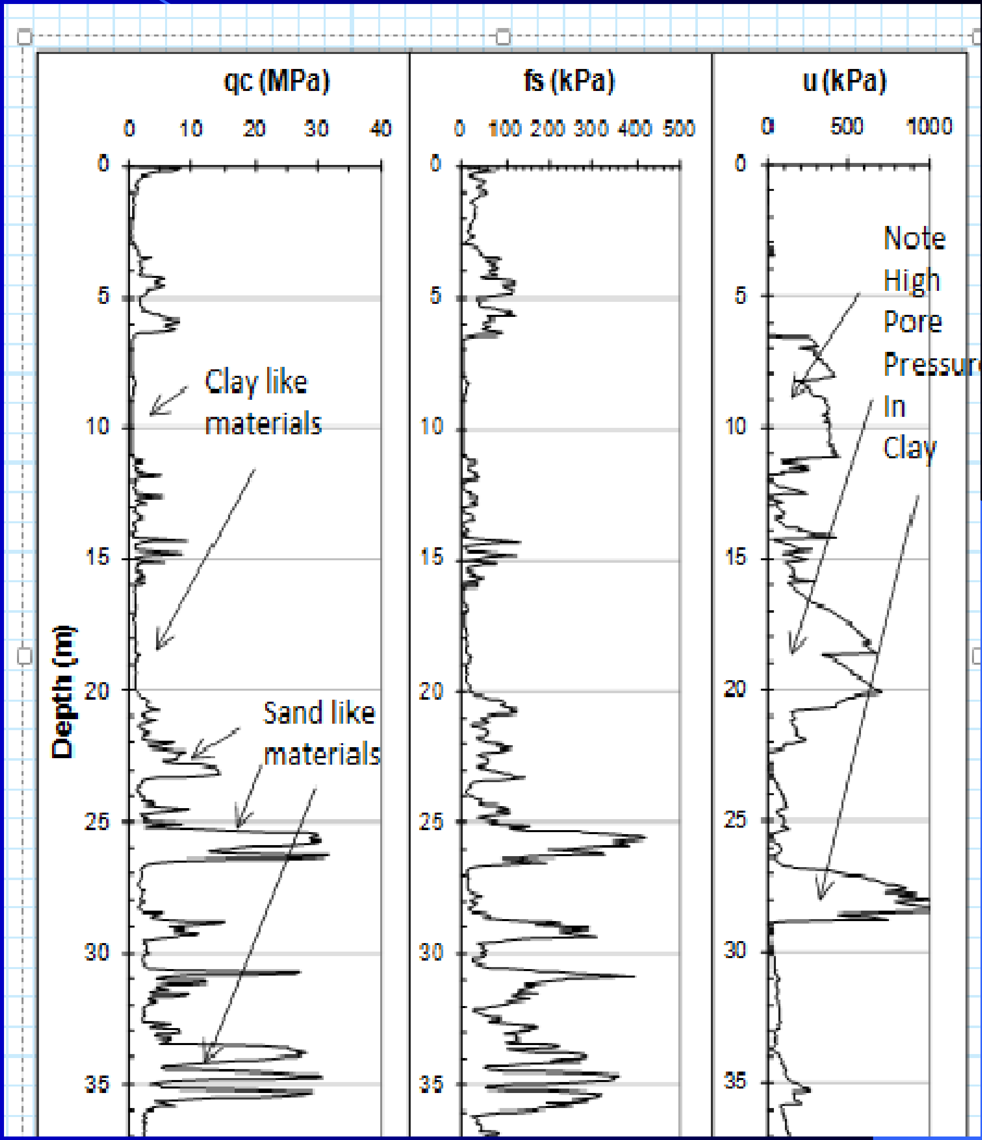
Estimation of Frequency Liquefaction Potential

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

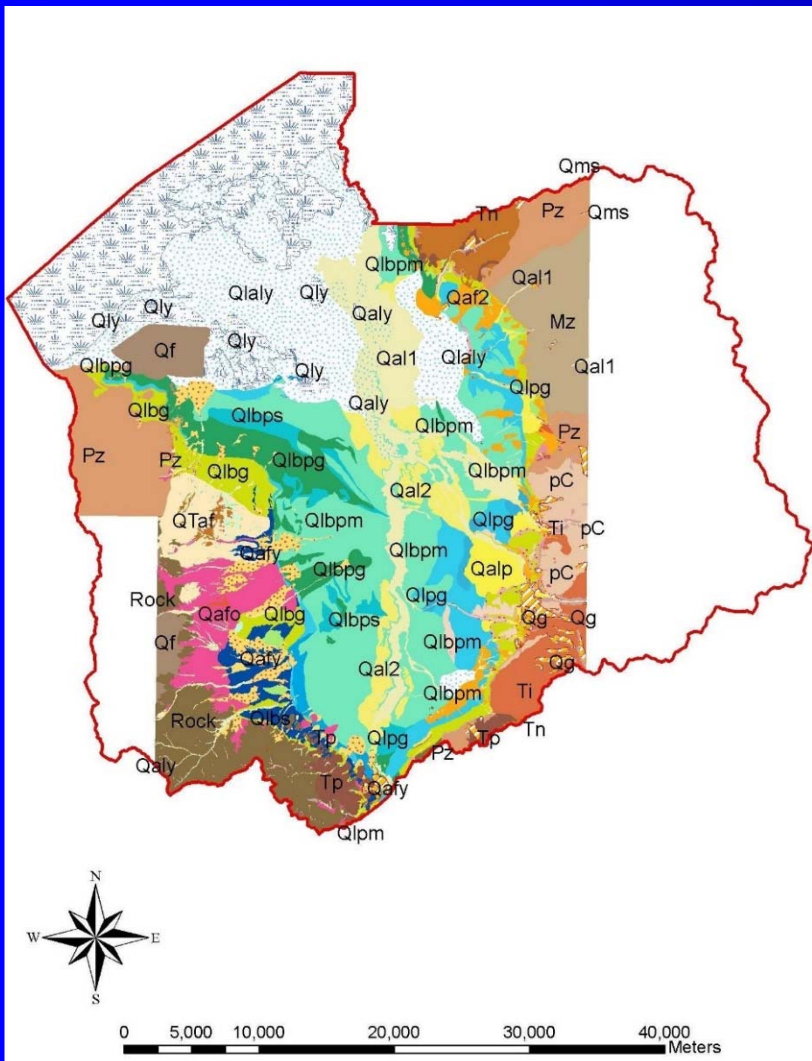


Estimation of Frequency Liquefaction Potential

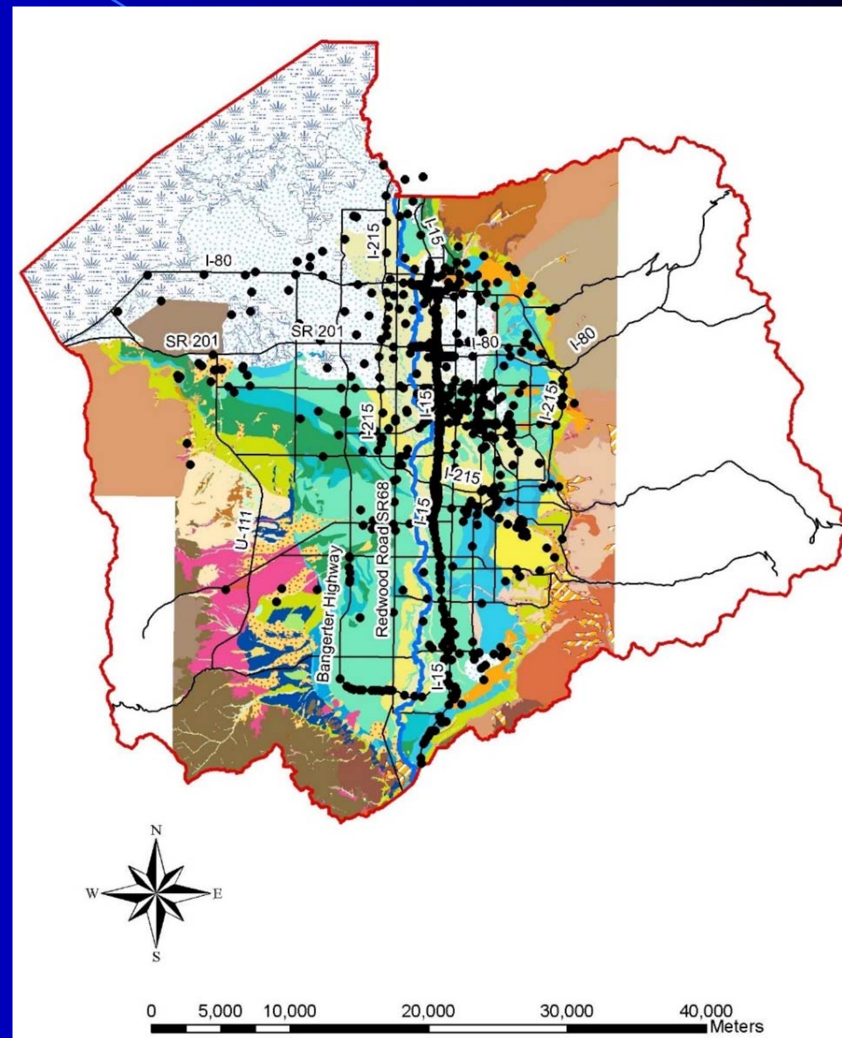
- Subsurface data collection
  - Cone Penetrometer Testing (CPT)



Estimation of Frequency Liquefaction Potential

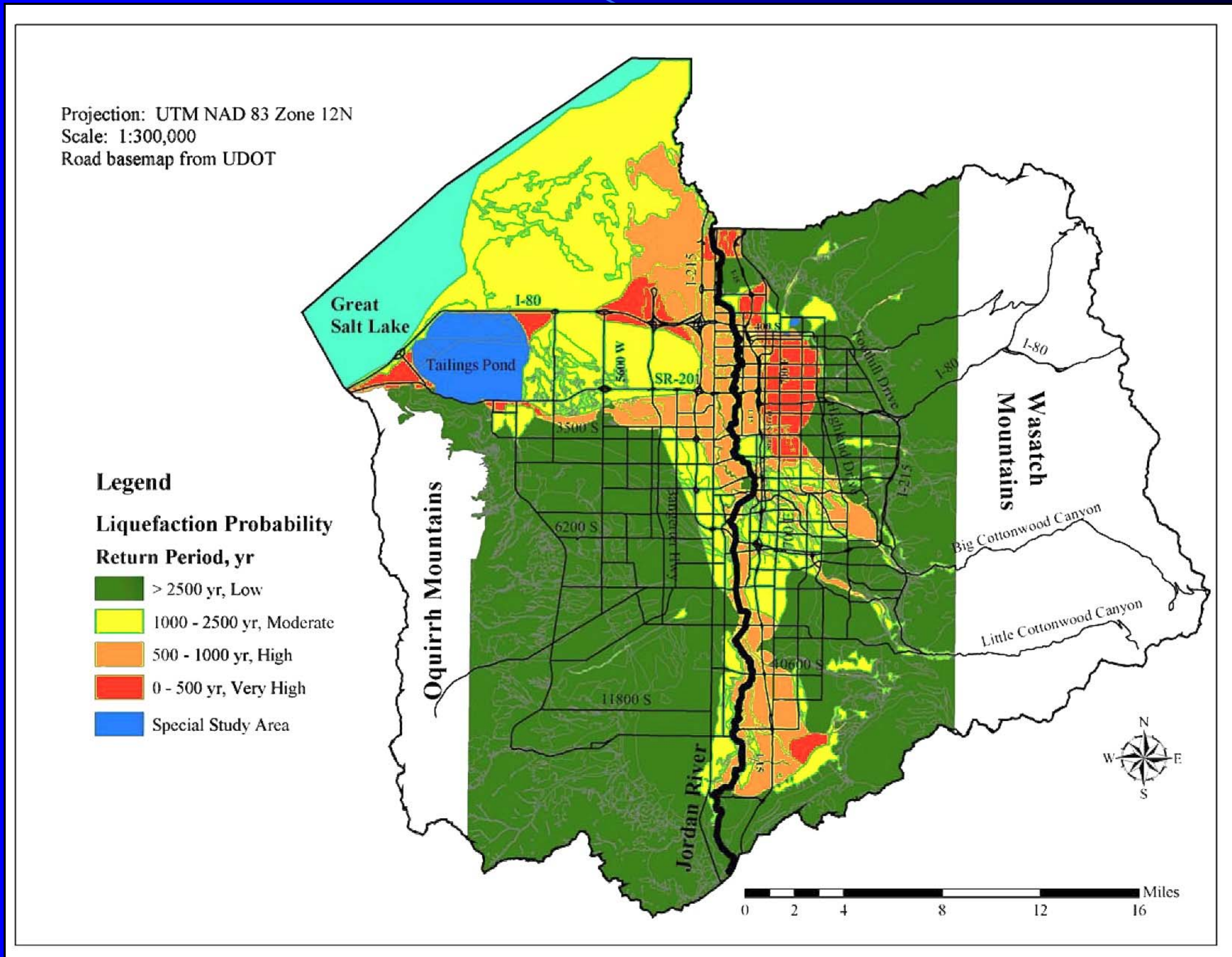


Geology Map

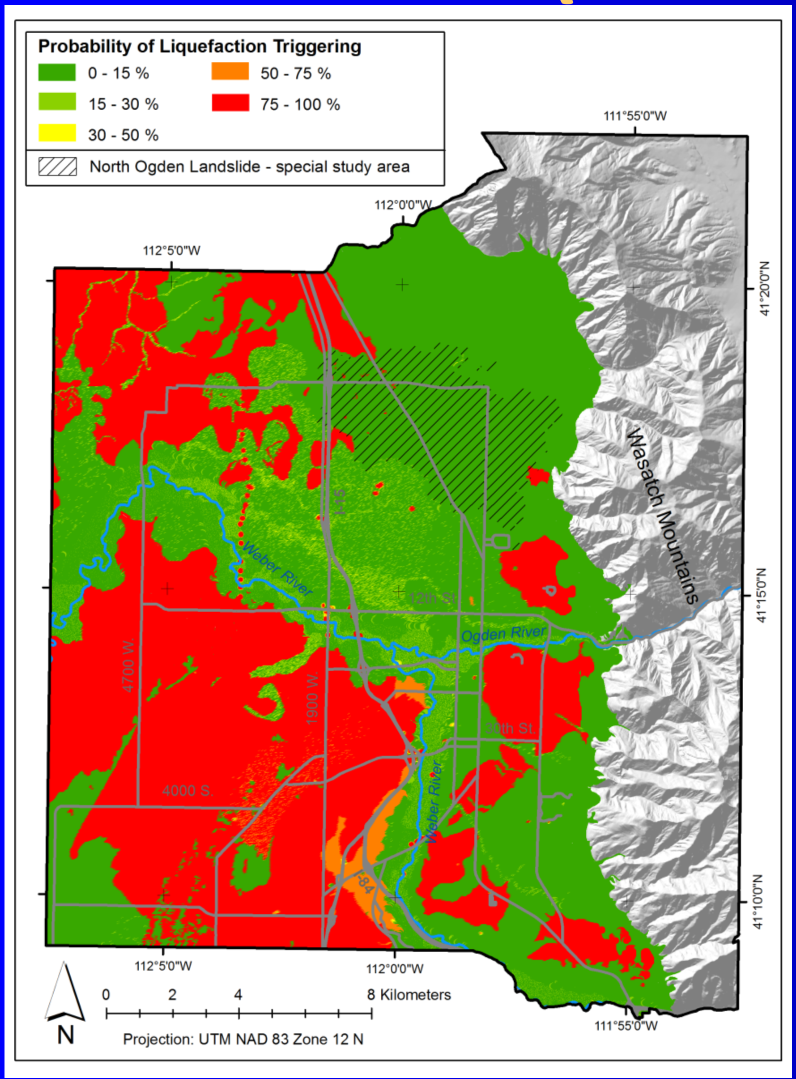


Borehole Map

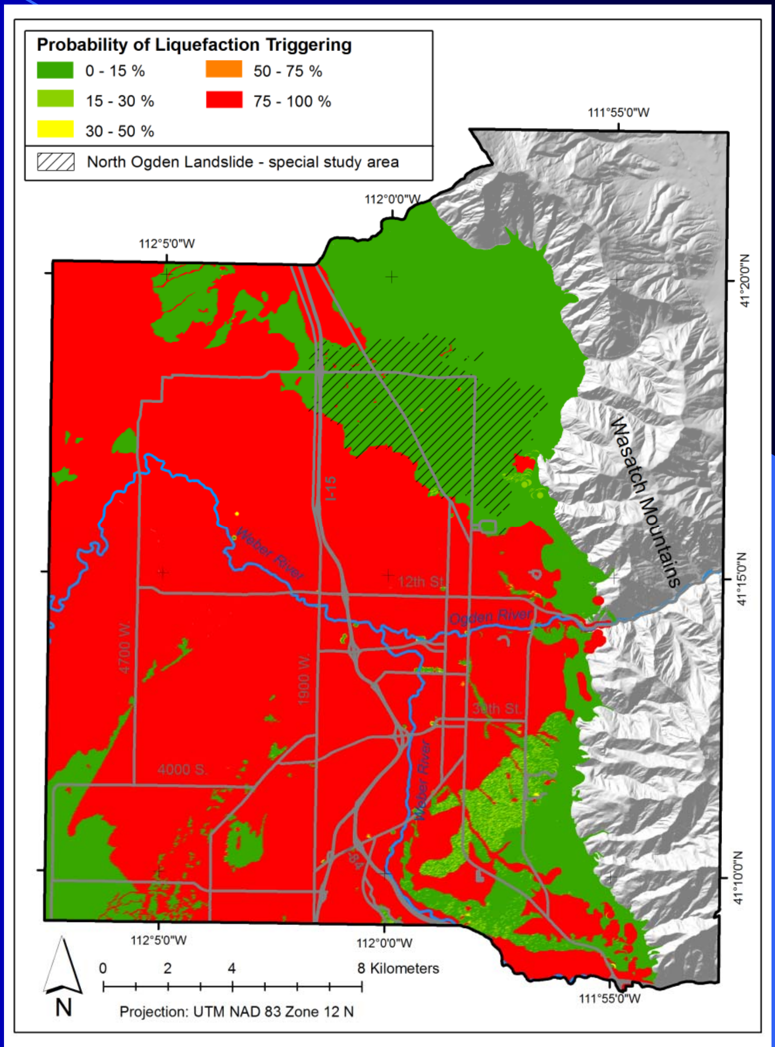
Estimation of Frequency (Liquefaction Return Period)



Liquefaction Potential Maps (Weber County)



Median probabilities of P_L, 500-year seismic event



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

Topics

- Liquefaction Damage
- Types of Liquefaction Maps
- Estimation of Frequency
- Estimation of Liquefaction Potential
- **Estimation of Ground Displacement**
- Estimation of Settlement
- Performance-Based Hazard Ordinances

Estimation of Ground Displacement

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

  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.

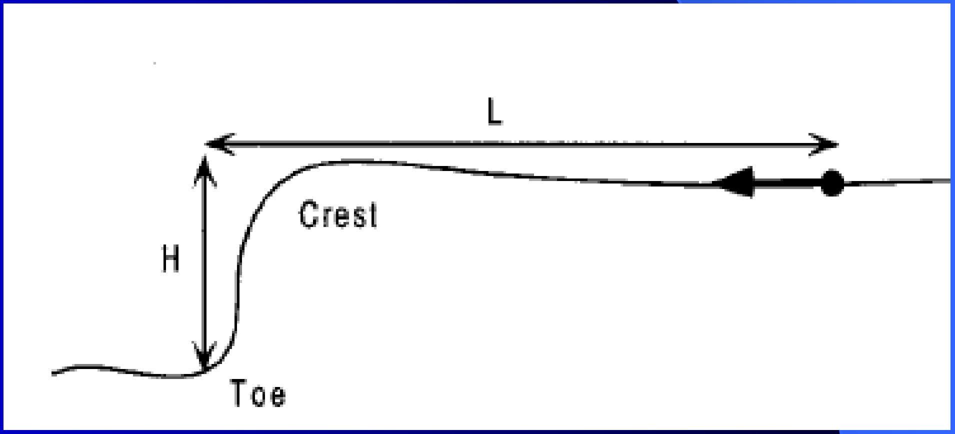
  – P[A,M,R] = joint probability density function of peak ground acceleration, magnitude and source distance.

Estimation of Ground Displacement (Salt Lake Valley)

Youd, Hansen, Bartlett (2002) Empirical Model

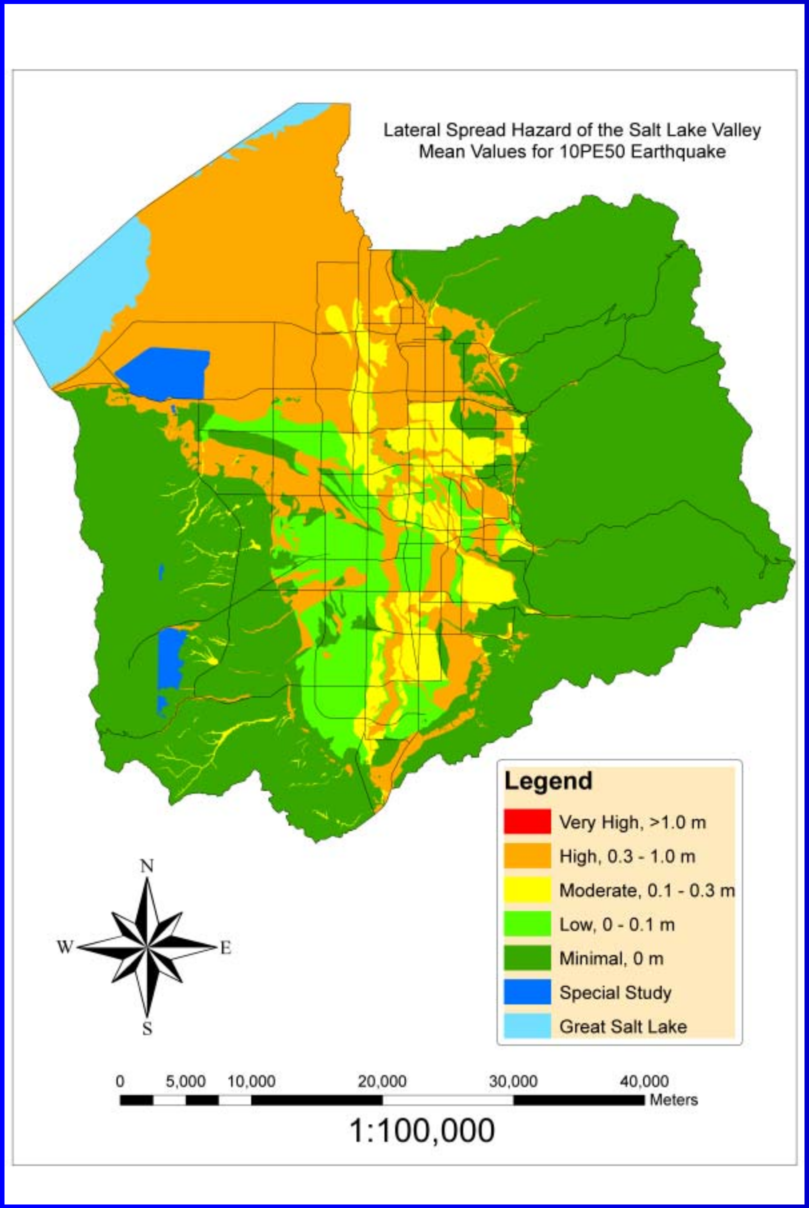
$$LogD_H = \begin{array}{c} b_o + b_{off}\alpha + b_1 M + b_2 LogR^* + b_3 R + b_4 LogW + b_5 LogS + b_6 LogT_{15} + \\ + b_7 Log(100 - F_{15}) + b_8 Log(D50_{15} + 0.1 \text{ mm}) \end{array}$$

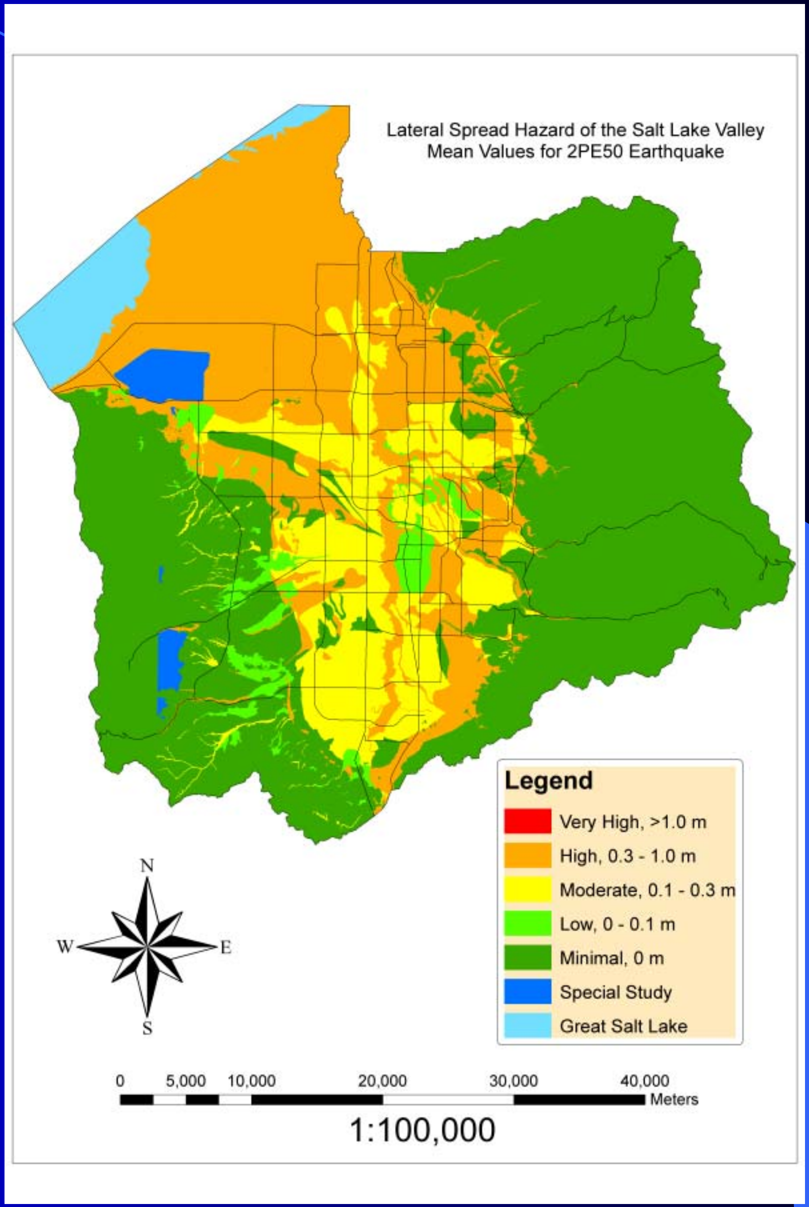
- Seismic Factors
  - *M, R*
- Topographic Factors
  - *W, S*
- Geotechnical Factors
  - T_{15}, F_{15}, $D50_{15}$



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

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

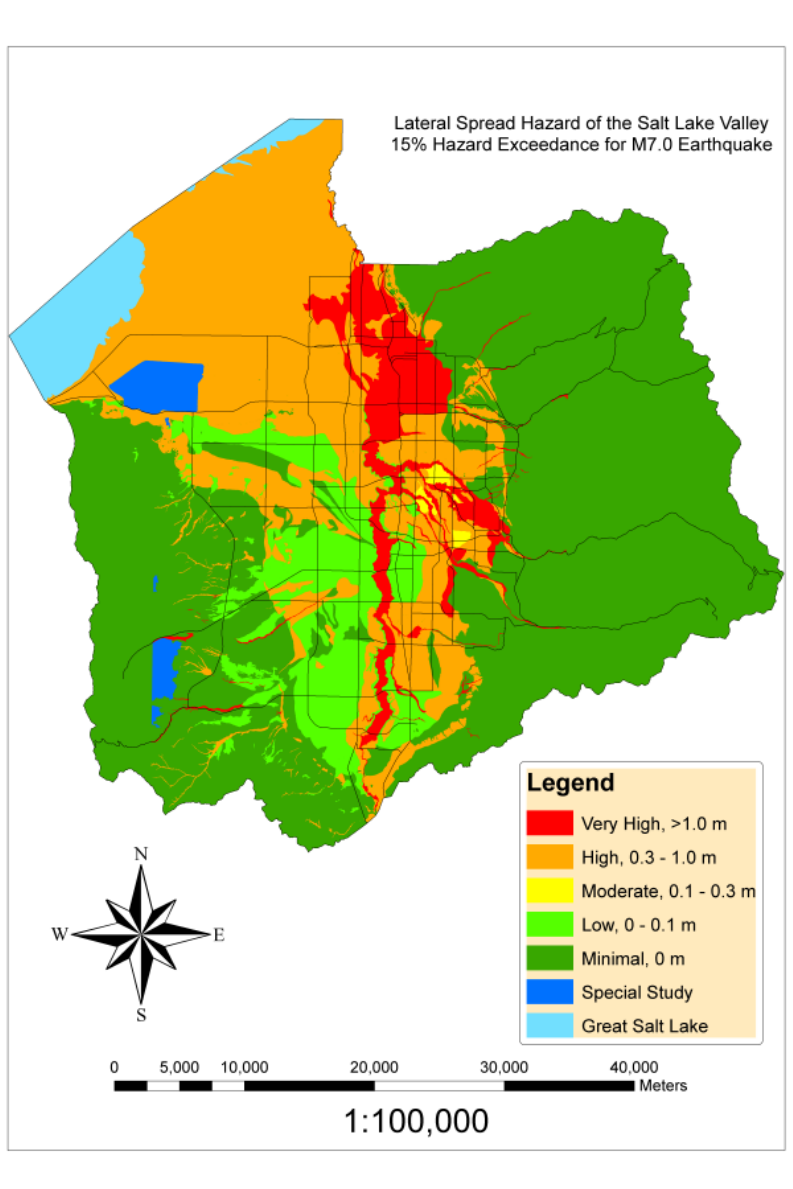




Ground Displacement (Salt Lake Valley)
Lateral Spread or 500 and 2500-year scenarios

M 7.0 Lateral spread displacement map

(85 percent chance of non-exceedance)



Estimation of Ground Displacement (Weber Co.)

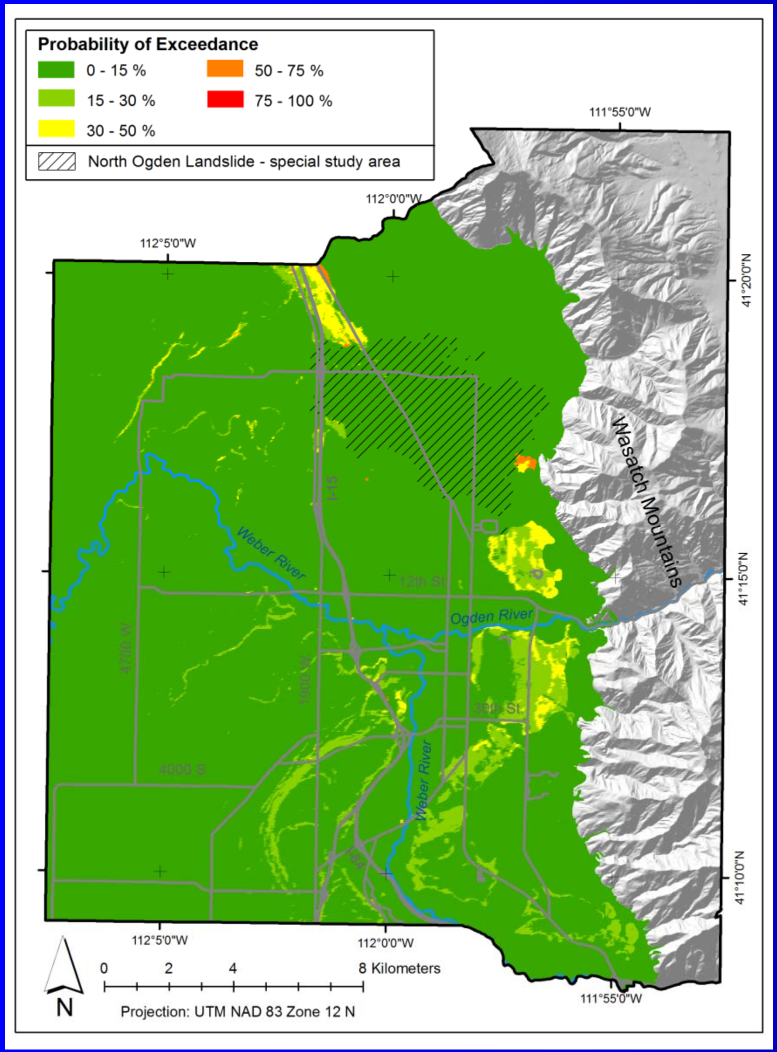
Gillins and Bartlett (2013) Empirical Model

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

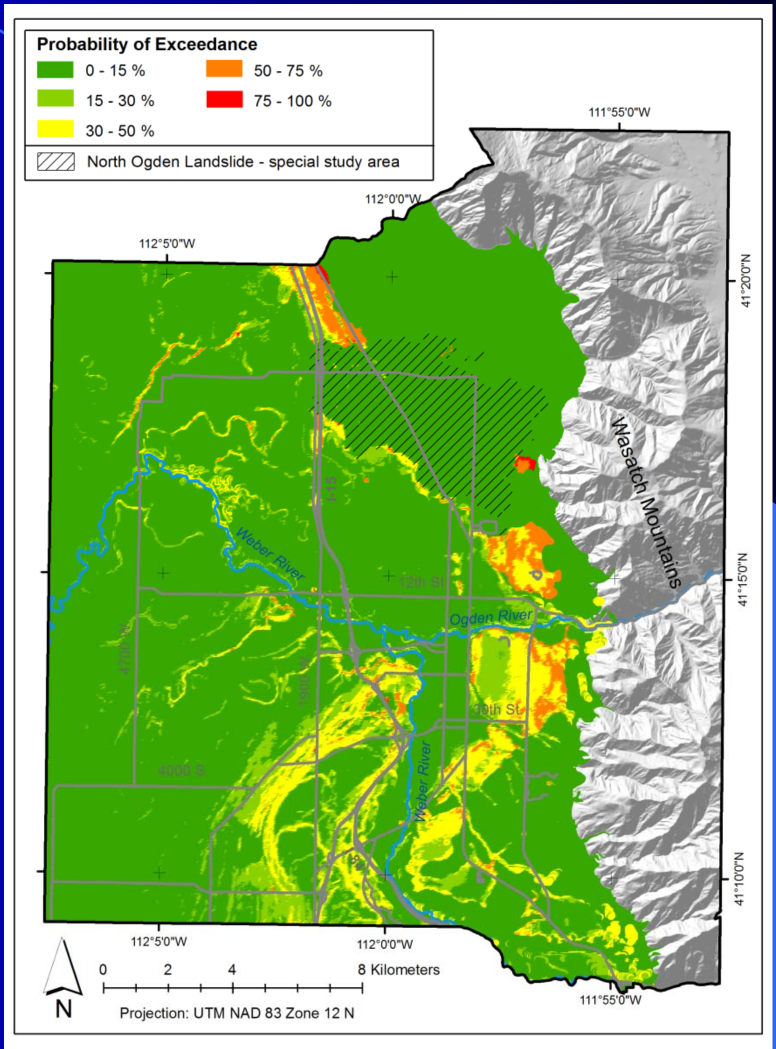
x_i = the portion (decimal fraction) of T_{15} in a borehole that has a soil index corresponding to the table below

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

Ground Displacement (Weber Co.)
Lateral Spread or 500-year scenario

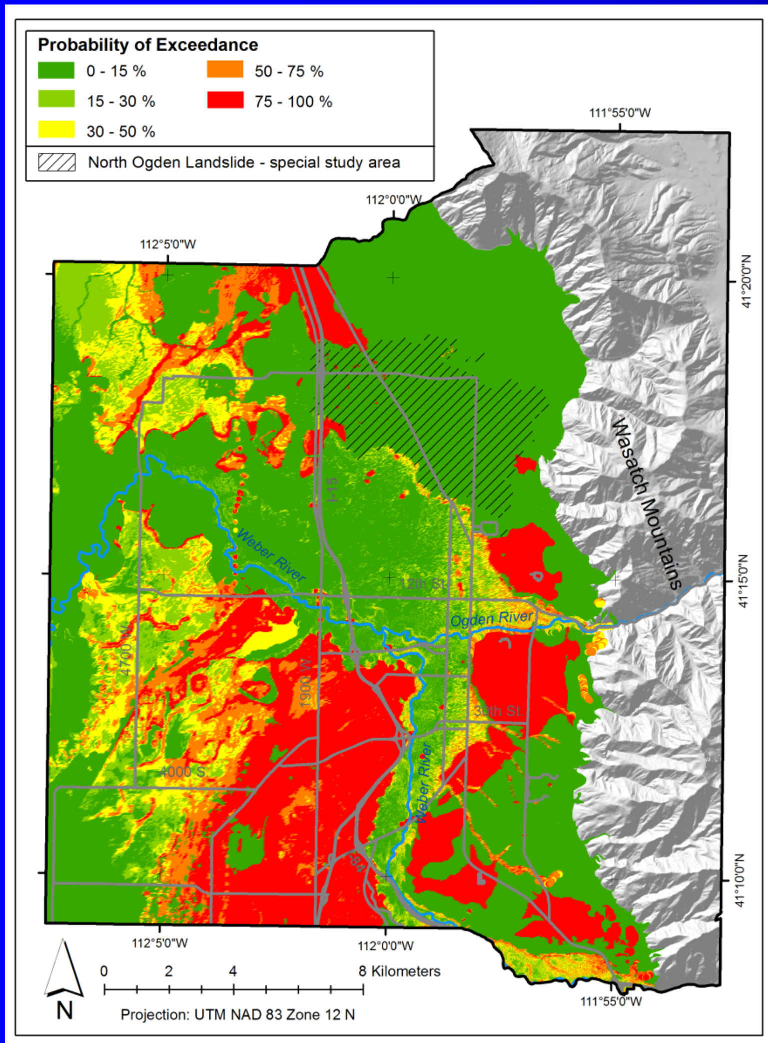


- Median probabilities of exceeding 0.3 m, 500-year event

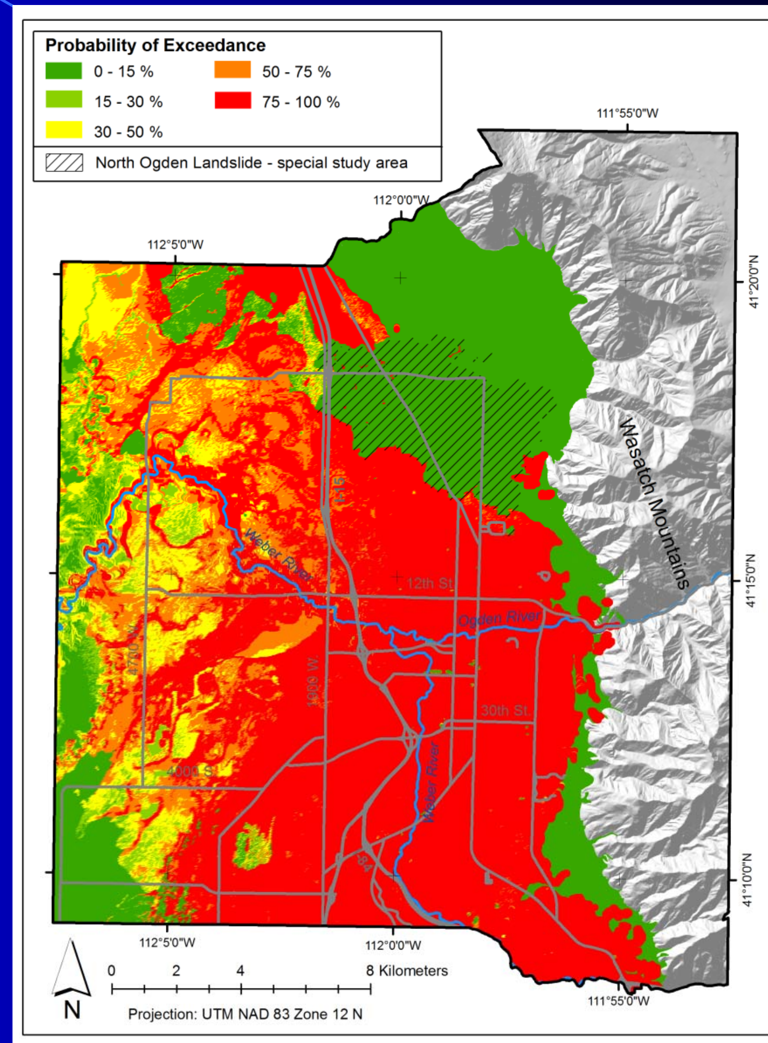


- 84th percentile probabilities, of exceeding 0.3 m, 500-year event

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



Median probabilities of exceeding 0.3 m, 2500-year event



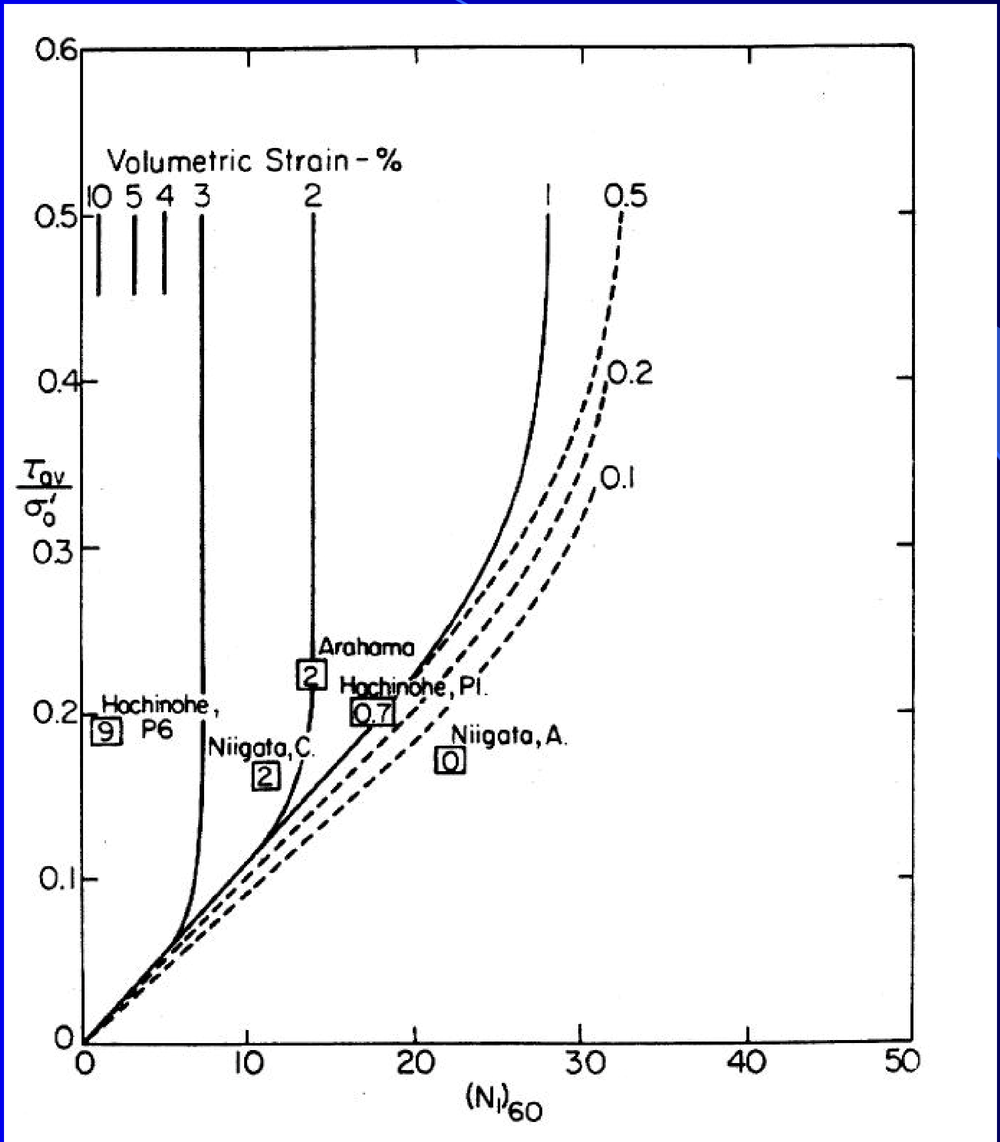
84th percentile probabilities, of exceeding 0.3 m, 2500-year event

Topics

- Liquefaction Damage
- Types of Liquefaction Maps
- Estimation of Frequency
- Estimation of Liquefaction Potential
- Estimation of Ground Displacement
- **Estimation of Settlement**
- Performance-Based Hazard Ordinances

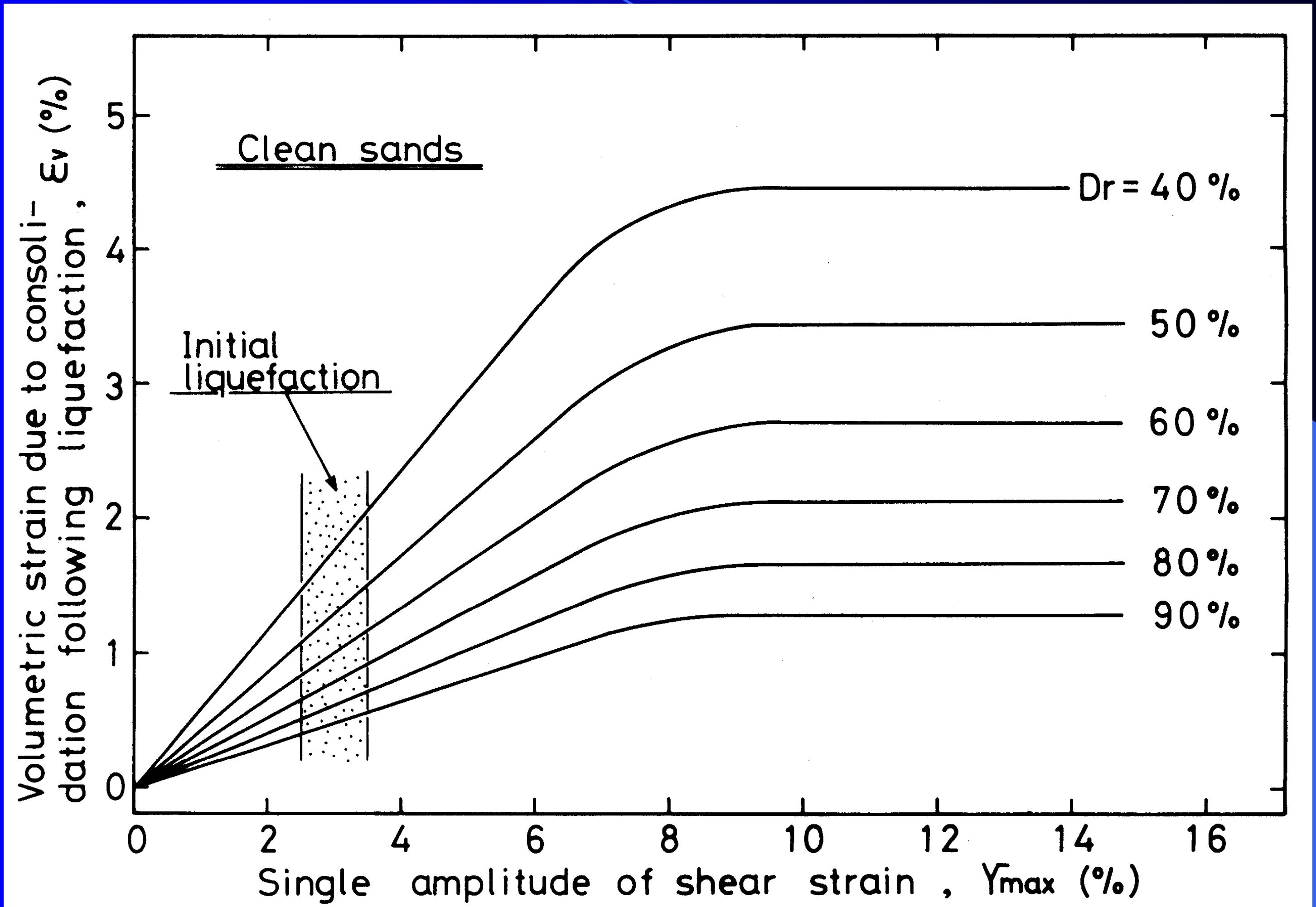
Estimation of Settlement

(Tokimatsu
And Seed, 1987)

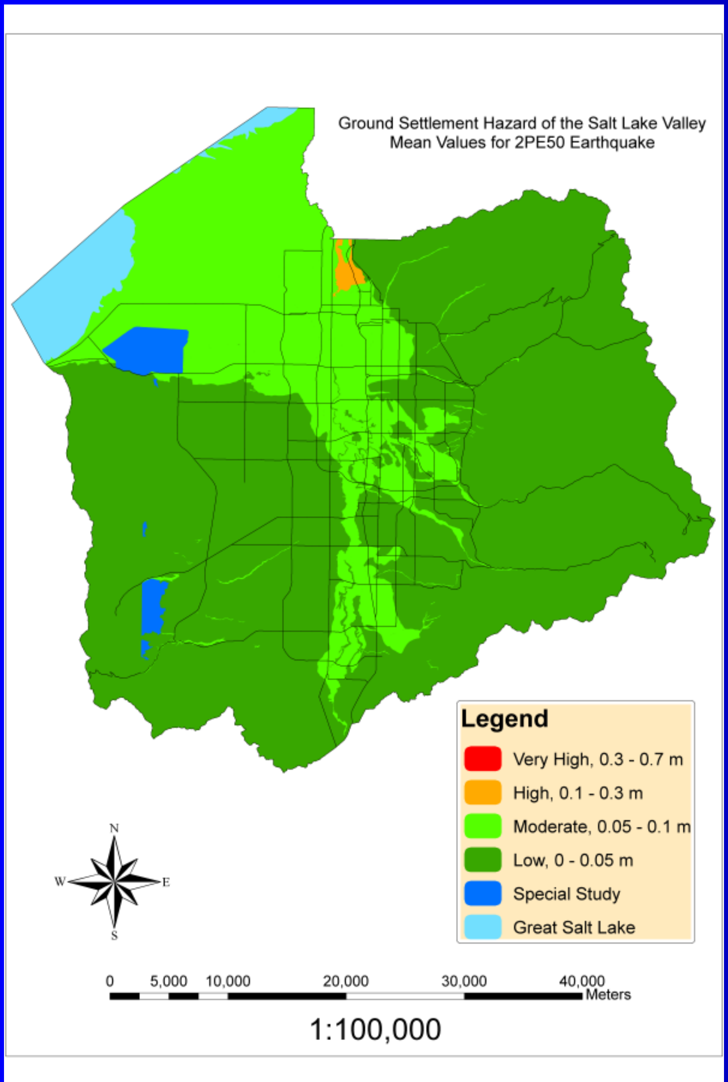


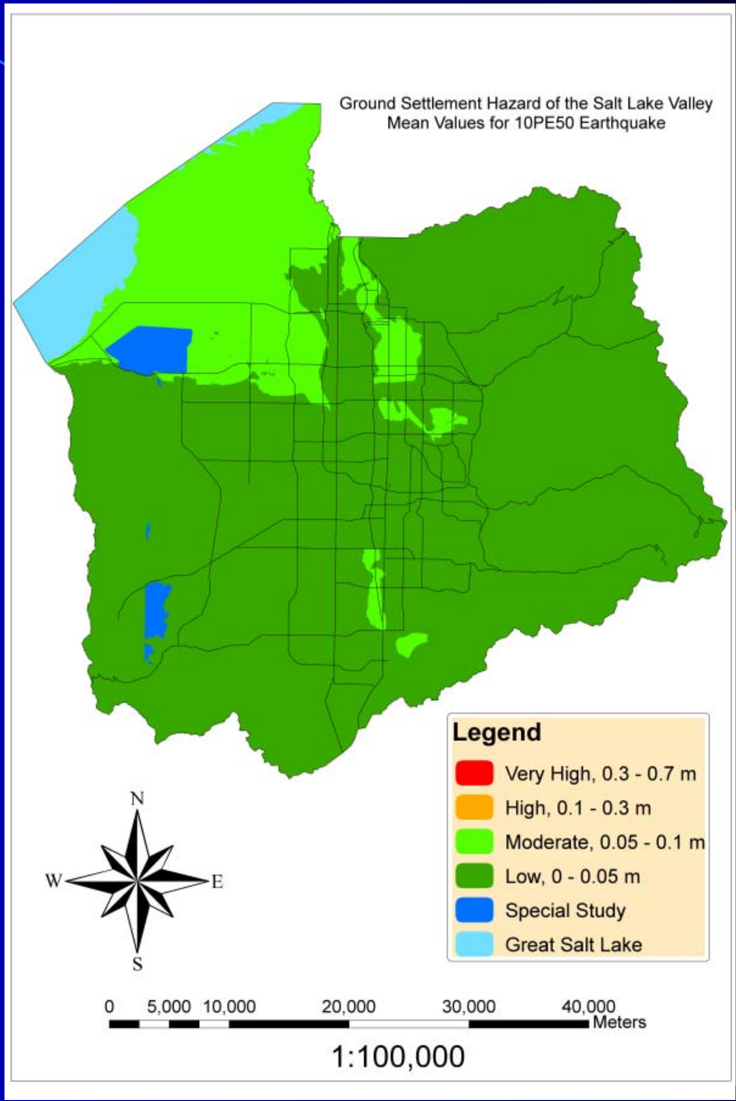
Estimation of Settlement

(Ishihara and Yoshimine 1992).



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





500-yr event

2500-yr event

Topics

- Liquefaction Damage
- Types of Liquefaction Maps
- Estimation of Frequency
- Estimation of Liquefaction Potential
- Estimation of Ground Displacement
- Estimation of Settlement
- **Performance-Based Hazard Ordinances**

Performance-Based Hazard Ordinances

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

- Level of seismic hazard <u>quantified</u> by frequency or return period of event.
- Facilities/structures/systems <u>classified</u> according to importance.
- Performance goals <u>defined</u> for each class
  - Input owners/stakeholders/public
- Performance goal(s) <u>evaluated</u> 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	Level 1	Level 1
	Moderately Frequent	Level 1	Level 1
	Infrequent	Level 1	Level 1
	Rare	Level 1	Level 1
Essential	Frequent	Level 1	Level 1
	Moderately Frequent	Level 1	Level 1
	Infrequent	Level 2	Level 2
	Rare	Level 2	Level 3
Important	Frequent	Level 1	Level 1
	Moderately Frequent	Level 1	Level 1
	Infrequent	Level 2	Level 3
	Rare	Level 2	Level 4
Routine	Frequent	NA	NA
	Moderately Frequent	NA	NA
	Infrequent	NA	NA
	Rare	NA	NA