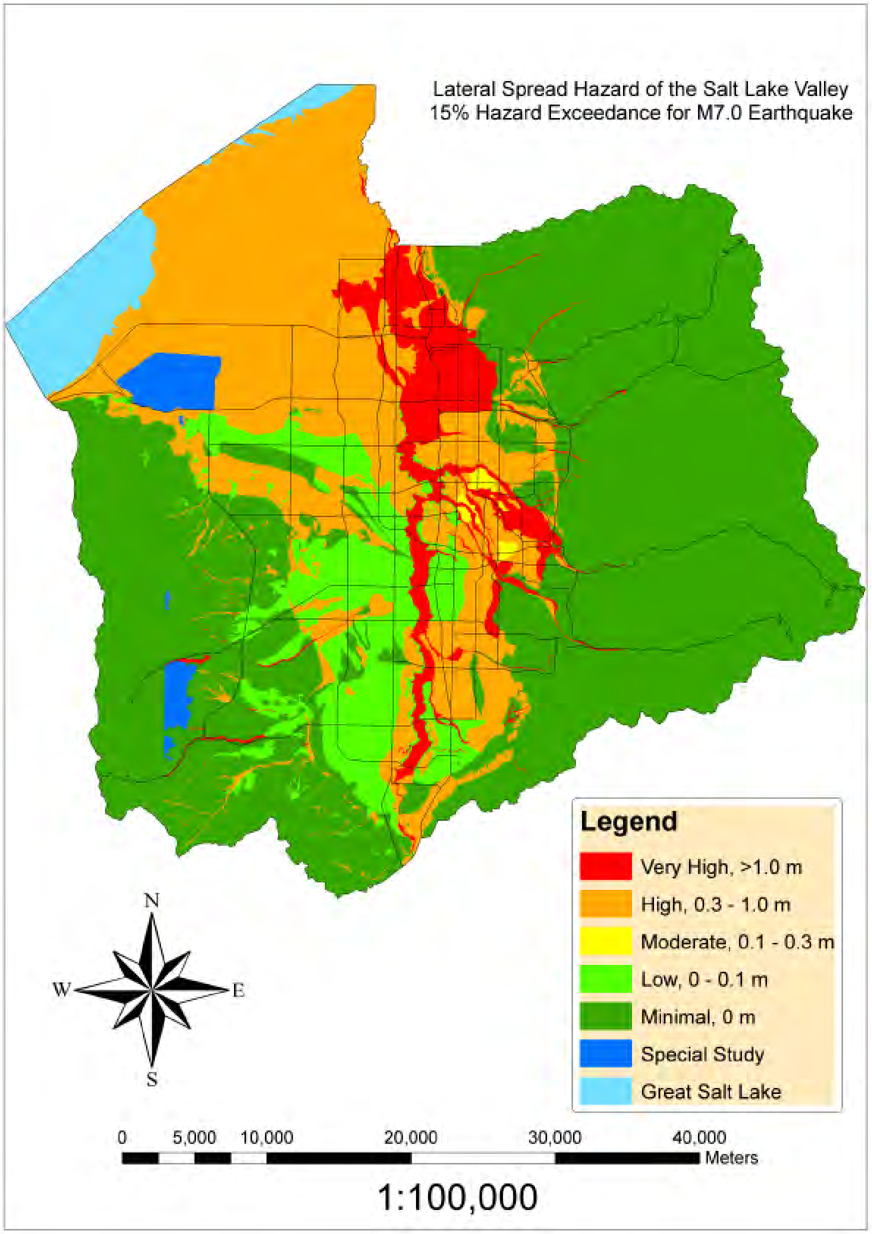
Utah Liquefaction Advisory Group (ULAG)



Progress Report on Liquefaction Working Group

February 8, 2010
Salt Lake City, Utah

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

ULAG Members and Participants

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

Aurelian Trandafir, UUGG

Jim Higbee, UDOT

Bill Turner, Earthtec

Ryan Cole, Gerhart-Cole

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

Status 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.)**

Status Previous Work

FY 2006

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

2.1.1 Done

2.1.2 Done

2.1.3 Done

2.1.4 Done

2.1.5 On Hold

2.1.6 Done

2.1.7 Done

2.1.8 Done

2.1.9 Done

Status Previous Work

FY 2007

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

2.1.1 Unfunded

2.1.2 Done

2.1.3 Done

2.1.4 Ongoing

FY 2008 (No Funding)

FY 2009 (No Funding)

FY 2010 (No Funding)

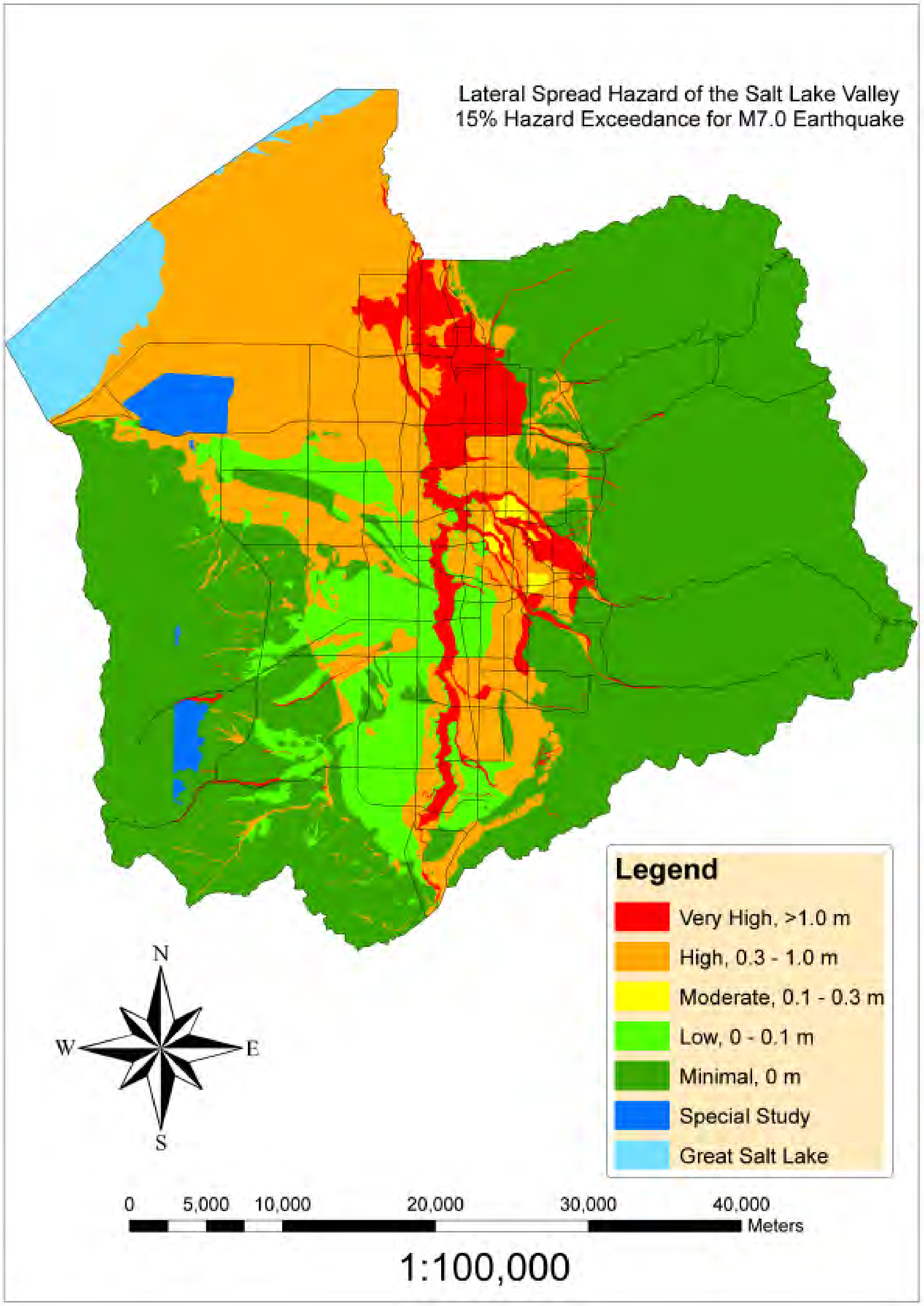
Other Items

- **Continued work on developing techniques for under-sampled units and uncertainty analysis**
    - Funded by U of U COE - $20 k
- **Performance Based GeoHazards Ordinance**
    - Draper City
    - EERI Presentation
- **Seismic Assessment of Salt Lake Valley Transportation Network (UDOT)**
    - Geotechnical database used for liquefaction evaluations
    - NEHRP site class map

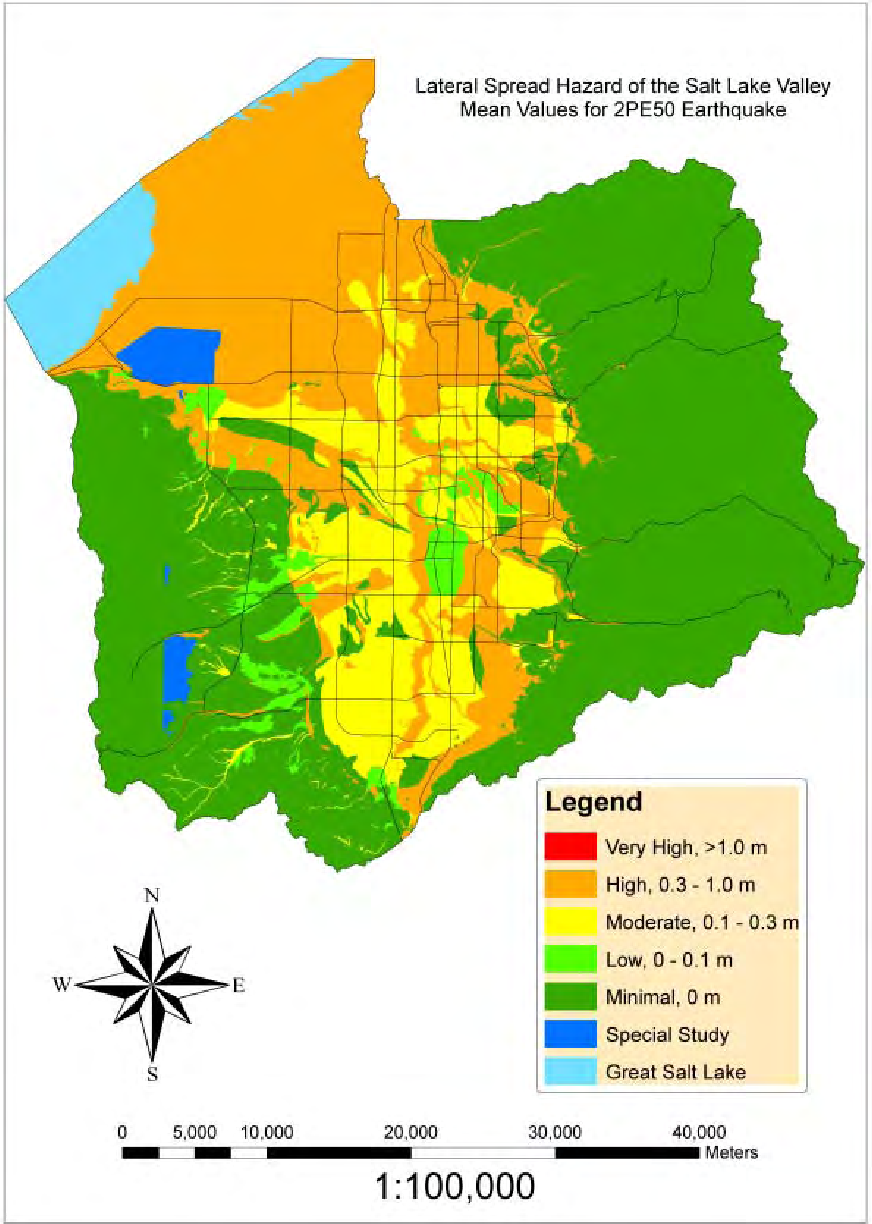
Other Items

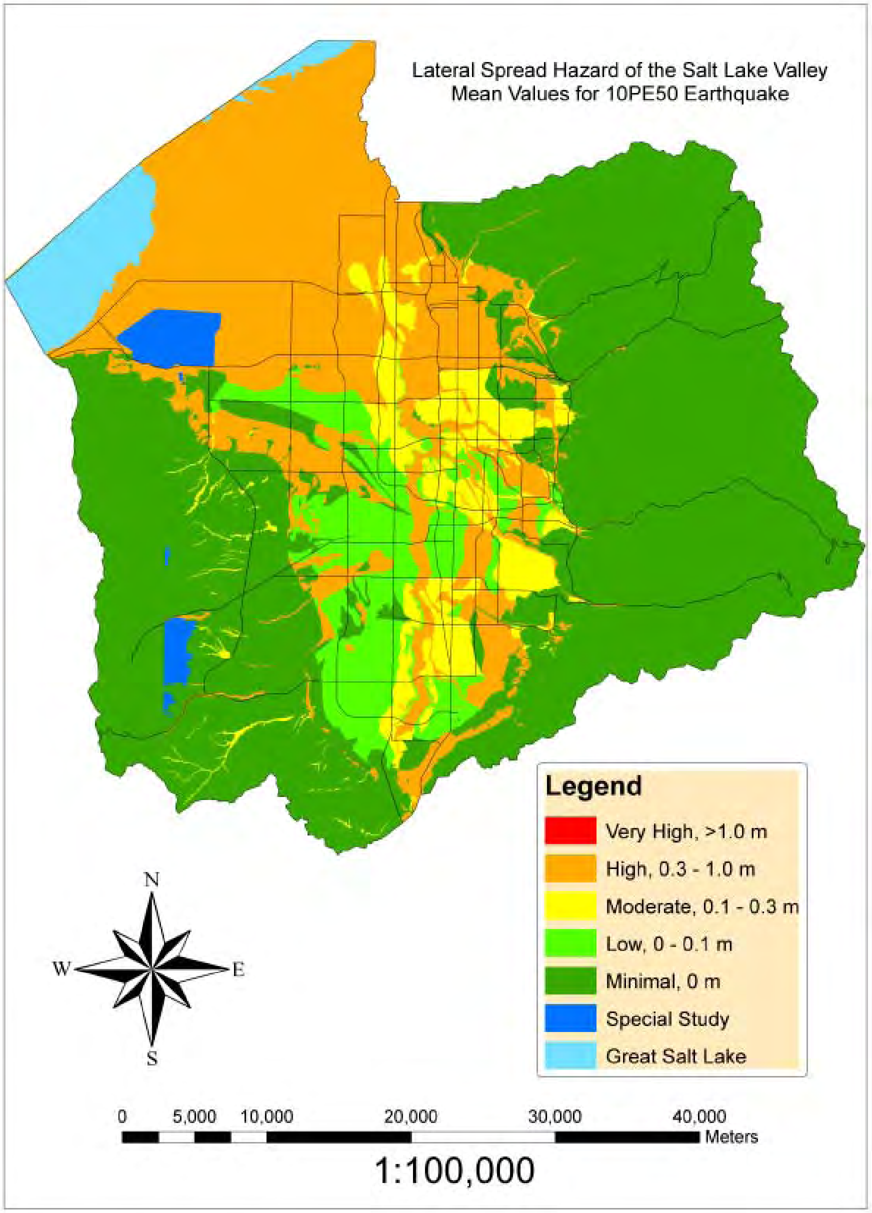
- **Mike Olsen is assistant professor at Oregon State**

M 7.0 Lateral spread displacement map

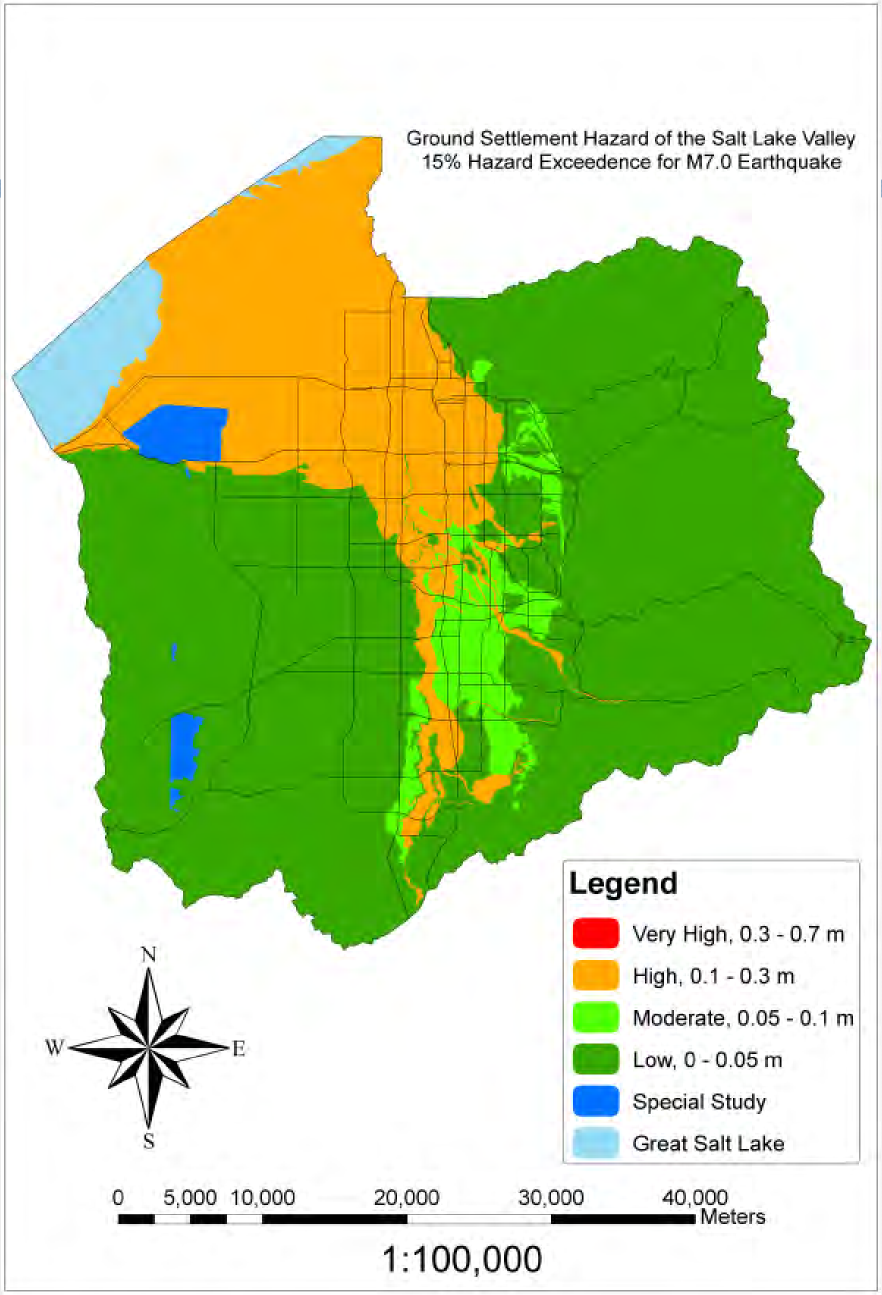


Probabilistic liquefaction potential maps for 2500 and 500-year return periods

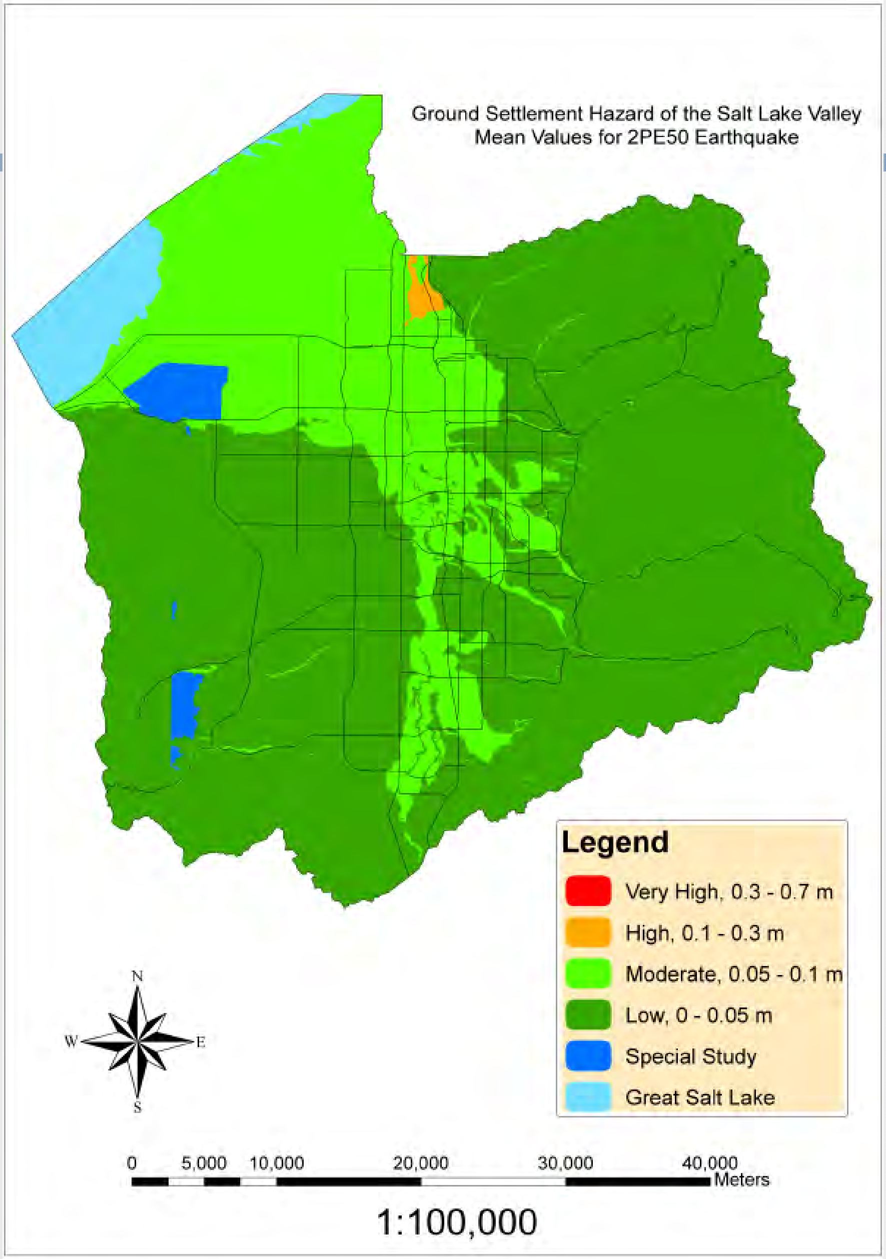


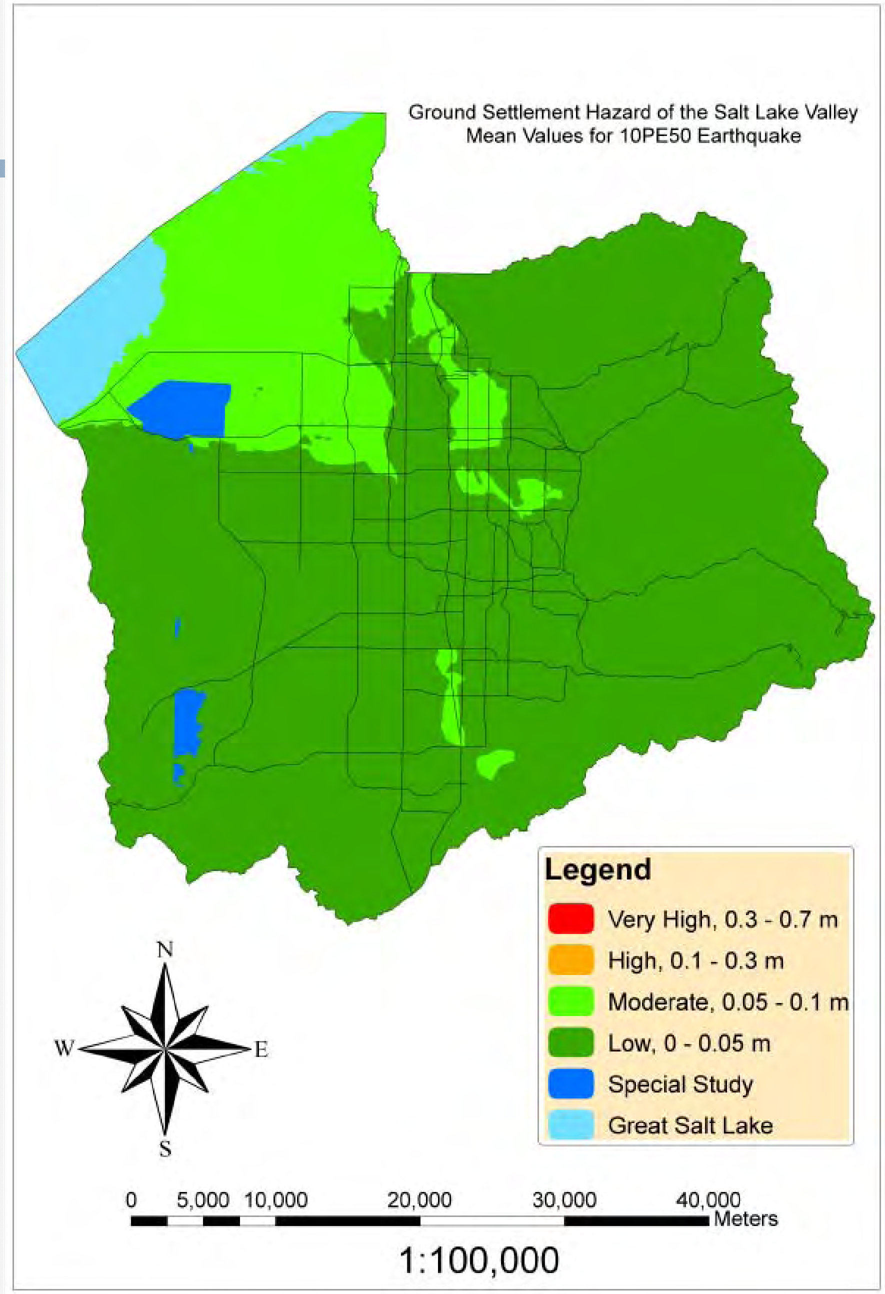


M 7.0 ground settlement map

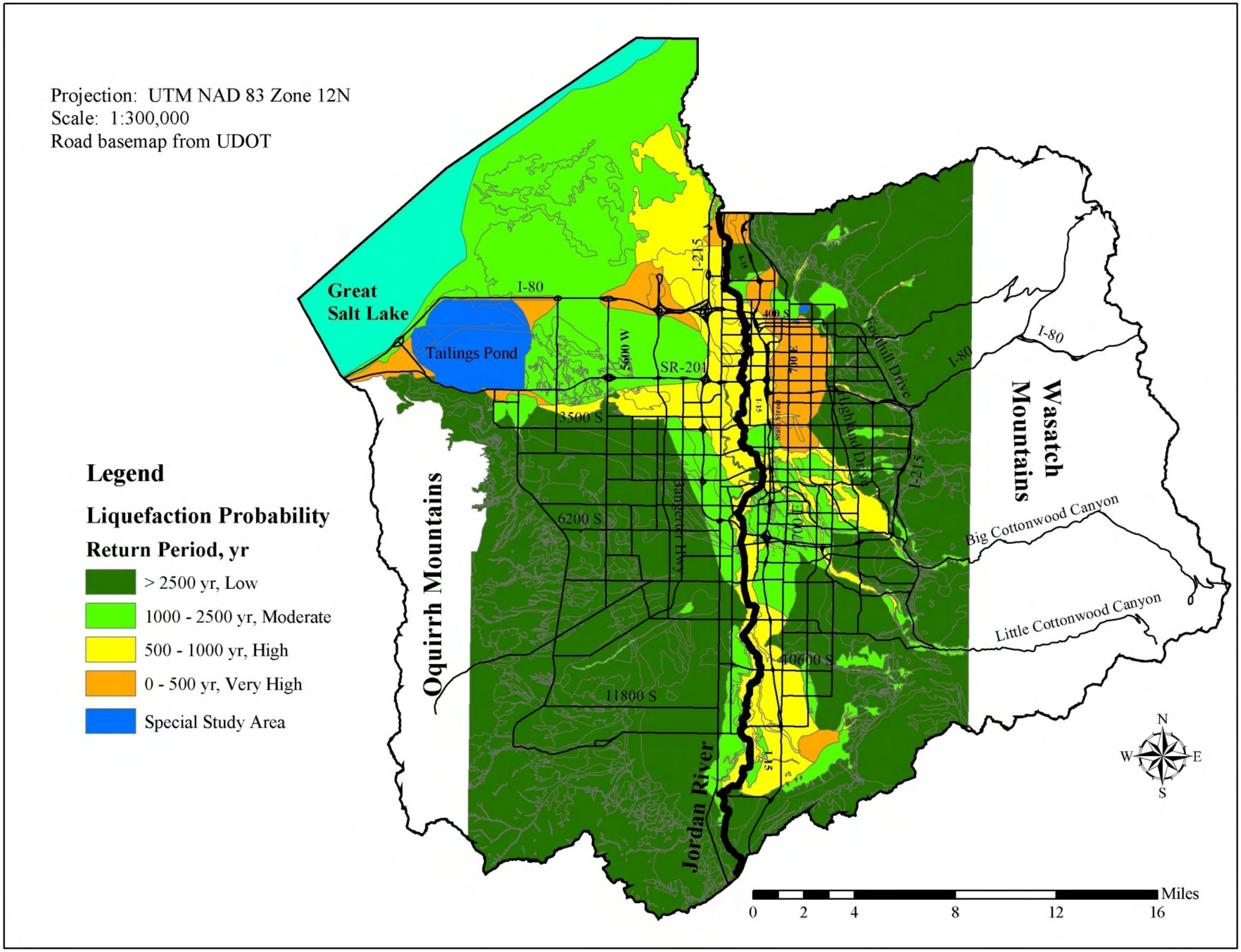


Probabilistic ground settlement maps for 2500 and 500-year return periods

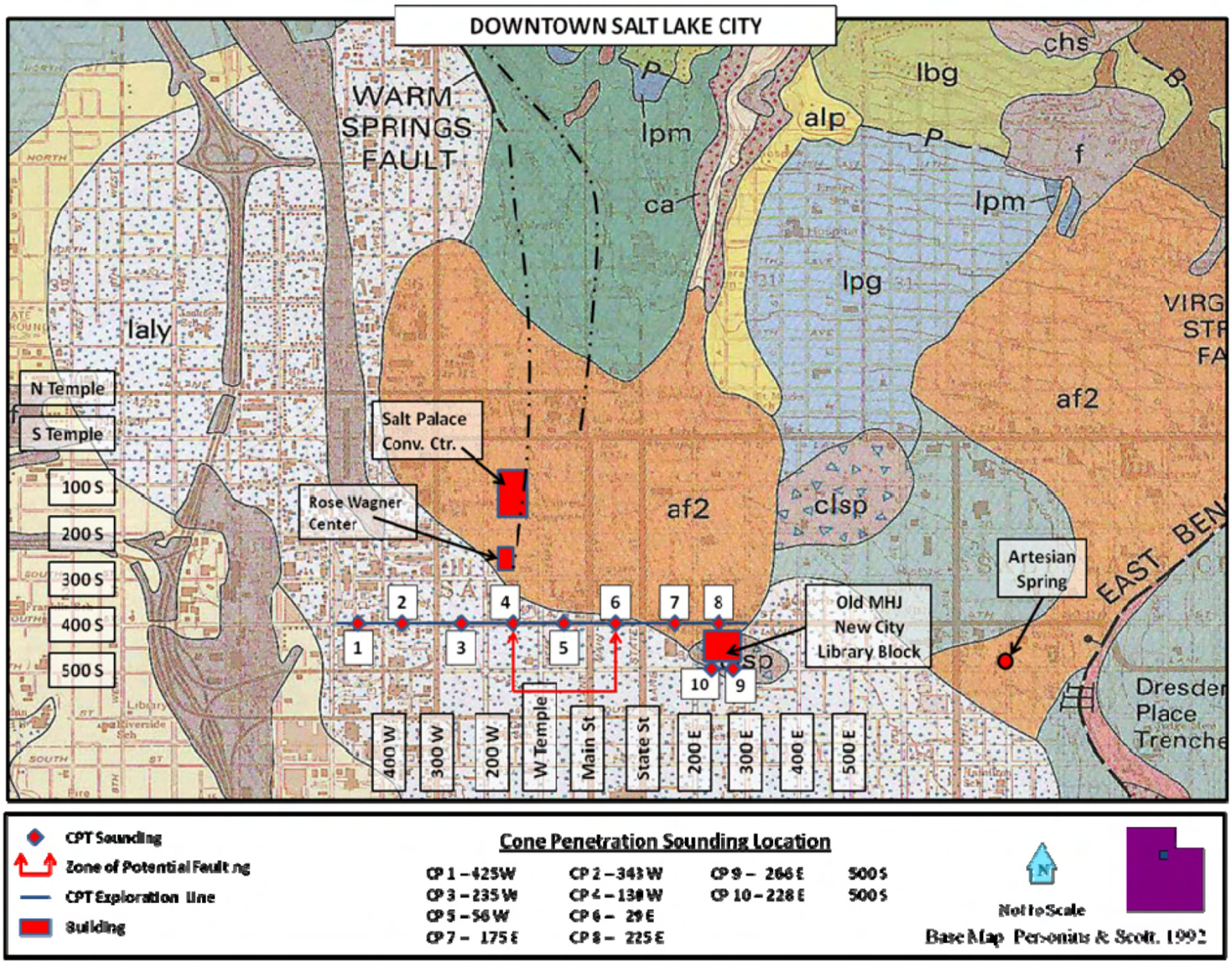




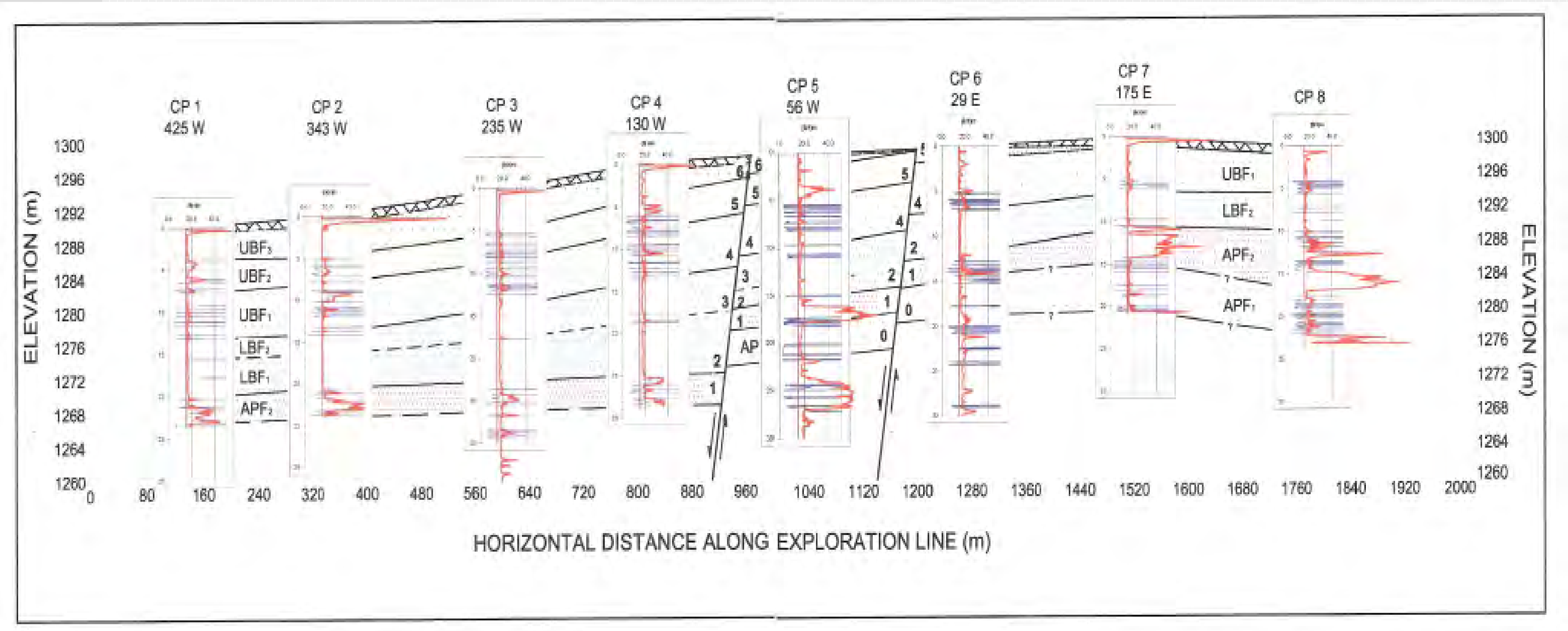
Probabilistic liquefaction potential map – (2002 Input)



Downtown Ground Failure Investigations



Downtown Ground Failure Investigations



Remaining Items

- Need USGS strong motion estimates to finalize aggregated probability of liquefaction and lateral spread maps.

- Final report for FY2006 and FY2007 due by end of March

2010 Plan

2.1.1 Task 1: Development of new techniques for mapping liquefaction hazard of under-sampled geologic units and quantifying the uncertainty associated with the liquefaction hazard and ground displacement estimates (University of Utah and Brigham Young University). 8
2.1.2 Task 2: Collect and analyze subsurface data for hazard mapping in Utah and Davis Counties (Brigham Young University and Utah Geological Survey)... 9
2.1.3 Task 3 Conduct additional CPT investigations to resolve origin of potential fault versus lateral spread offsets in downtown Salt Lake City (University of Utah).. 9
2.1.4 Task 4 Develop a performance-based method to help end user select appropriate return period for building and land use of the maps (University of Utah and Brigham Young University).......... 10
2.1.5 Task 5 Develop techniques for analyzing the Farmington Siding landslide complex in Davis County (University of Utah, Brigham Young University, Utah Geological Survey)...................... 10

Liquefaction-Induced Settlement Maps for the Salt Lake Valley

Daniel W. Hinckley

Utah Liquefaction Advisory Group

Utah Department of Natural Resources Building

February 8, 2010

Introduction

- Project funded by United States Geologic Survey (USGS)
  - National Earthquake Hazards Reduction Program (NEHRP)
  - NEHRP Award No. 04HQGR0026

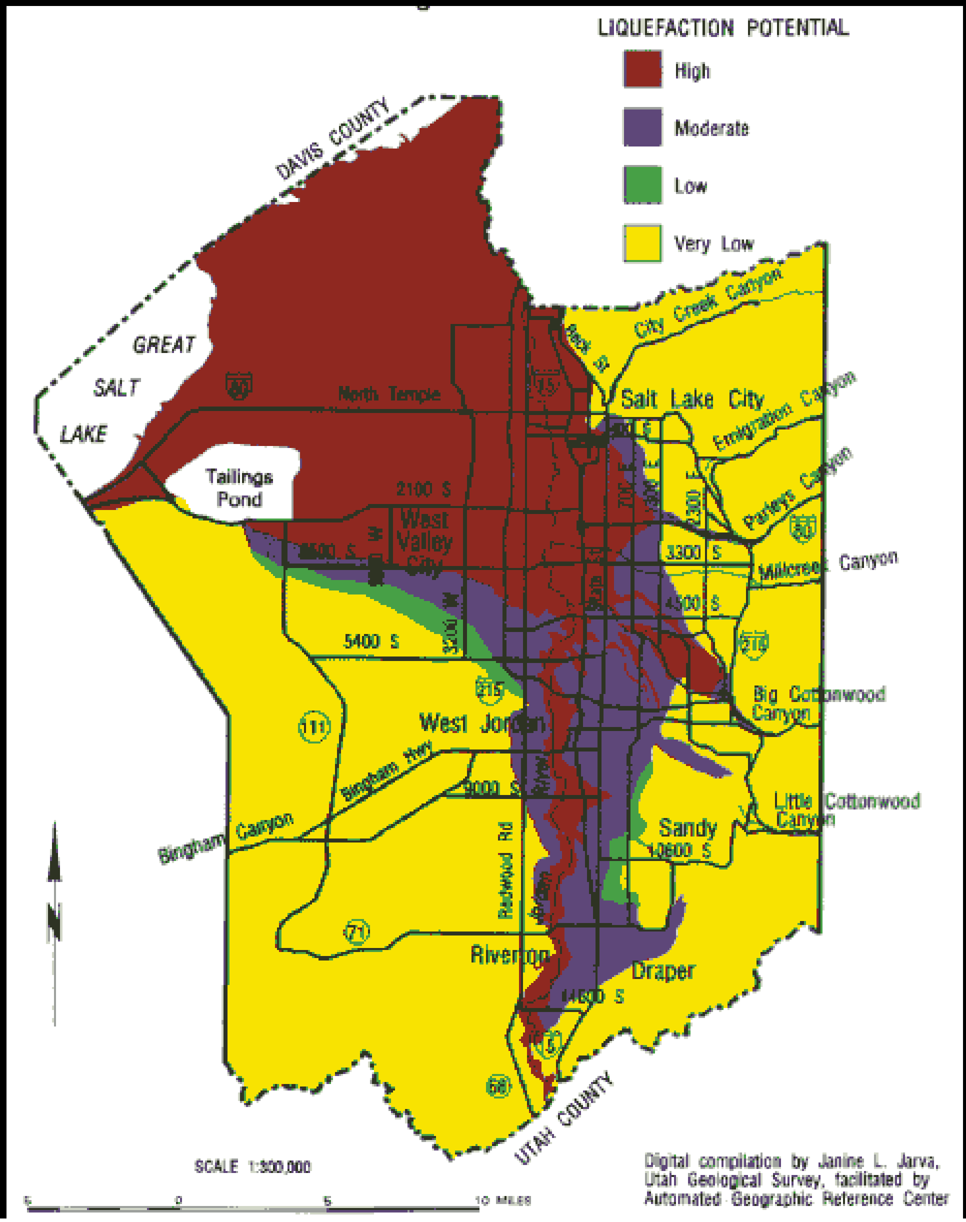
- Liquefaction-Induced Ground Settlement Map
  - Identify hazard severity across Salt Lake County
    - M7.0 Scenario Event on the Wasatch fault
    - Probabilistic 2% PE in 50 years (2,475-year return period)
    - Probabilistic 10% PE 50 years (475-year return period)

USGS science for a changing world

nehrp

Previous Liquefaction Mapping for the Salt Lake Valley

- Liquefaction Potential
  - Anderson et al., 1987
  - Solomon et al., 2004
  - Erickson et al., 2007
- Lateral Spread (northern half only)
  - Bartlett et al., 2005
  - Olsen et al., 2007
- Input/Data Sources
  - Geologic Mapping
  - Limited Geotechnical Database
  - Extensive Geotechnical Database
  - Probabilistic Input Ground Motions
  - Deterministic Input Ground Motions
- Analyses
  - Seed and others (1982, 1985, 2003)
  - LSI (Youd and Perkins, 1987)
  - HAZUS (FEMA, NIBS, 1999)



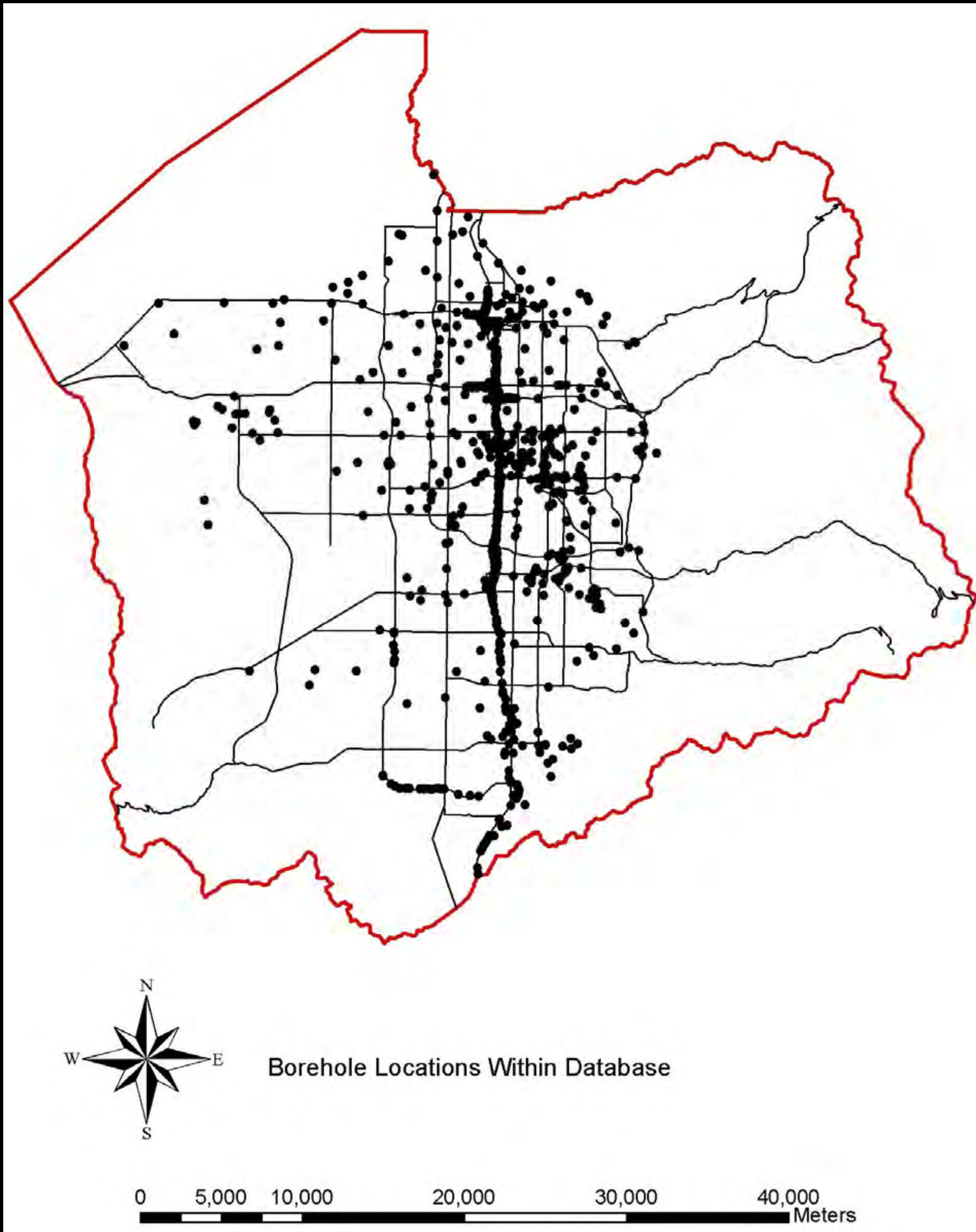
Goal of this study:

Create the first liquefaction-induced settlement maps developed in Utah using both geotechnical and geologic subsurface data and probabilistic estimates of strong ground motion

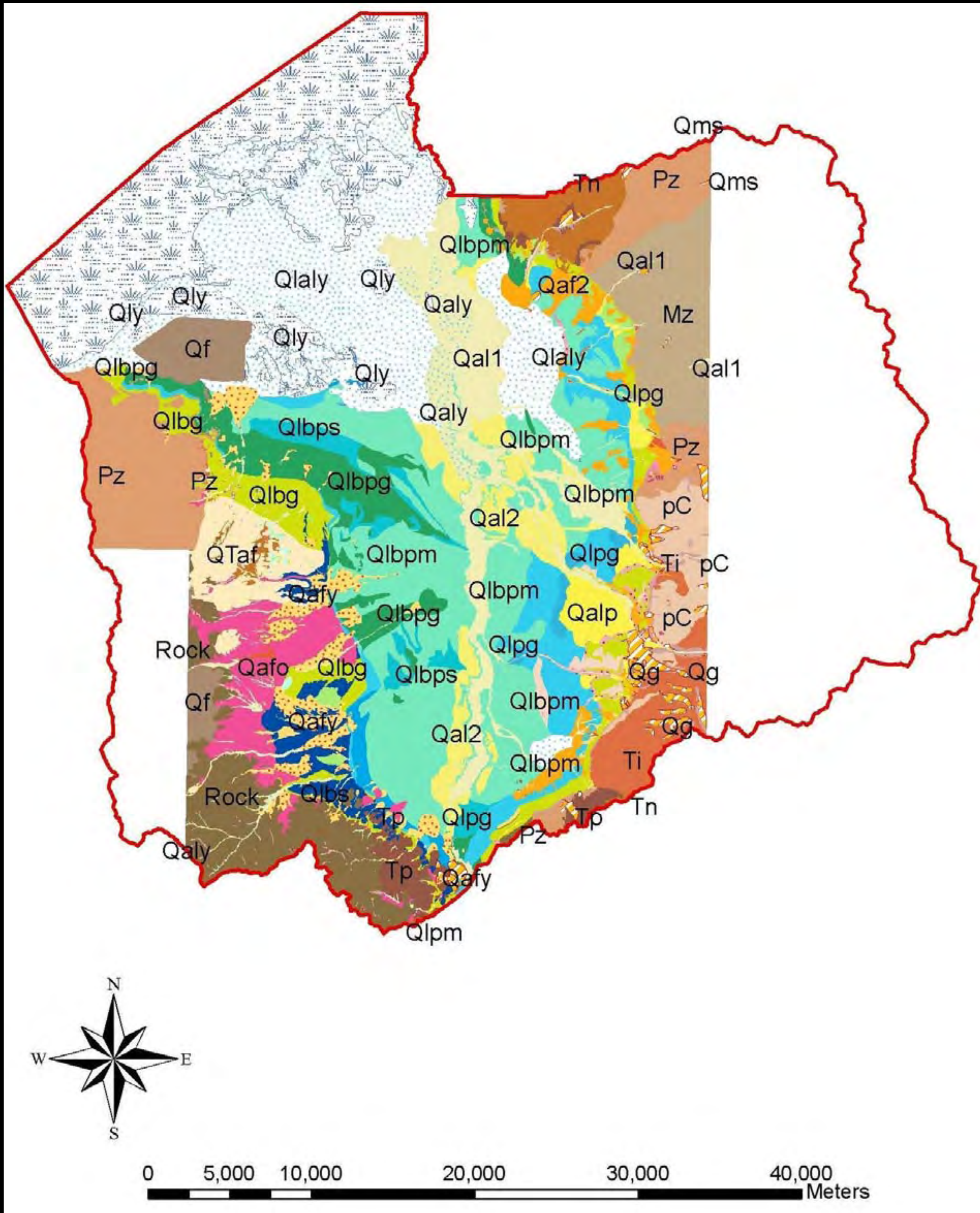
Map Development: Geotechnical Database

963 Boreholes, 50 Years of Exploration

- Detailed Exploration Logs
  - STP Results
  - Soil Profiles, Descriptions
  - Groundwater Level
- Corresponding Laboratory Data
  - Fines Contents
  - Mean Grain Sizes
  - Unit Weights
- Shear Wave Velocities
- Represent all Major Geologic Units
- Data Provided by UDOT, Consultants and Various Cities



Borehole Data Provided by UDOT, Consultants and Various Cities



Represent all Major Geologic Units

Modified from Personius and Scott, 1992; Biek et al., 2004; and Miller, 1980

Map Development: Input Ground Motion

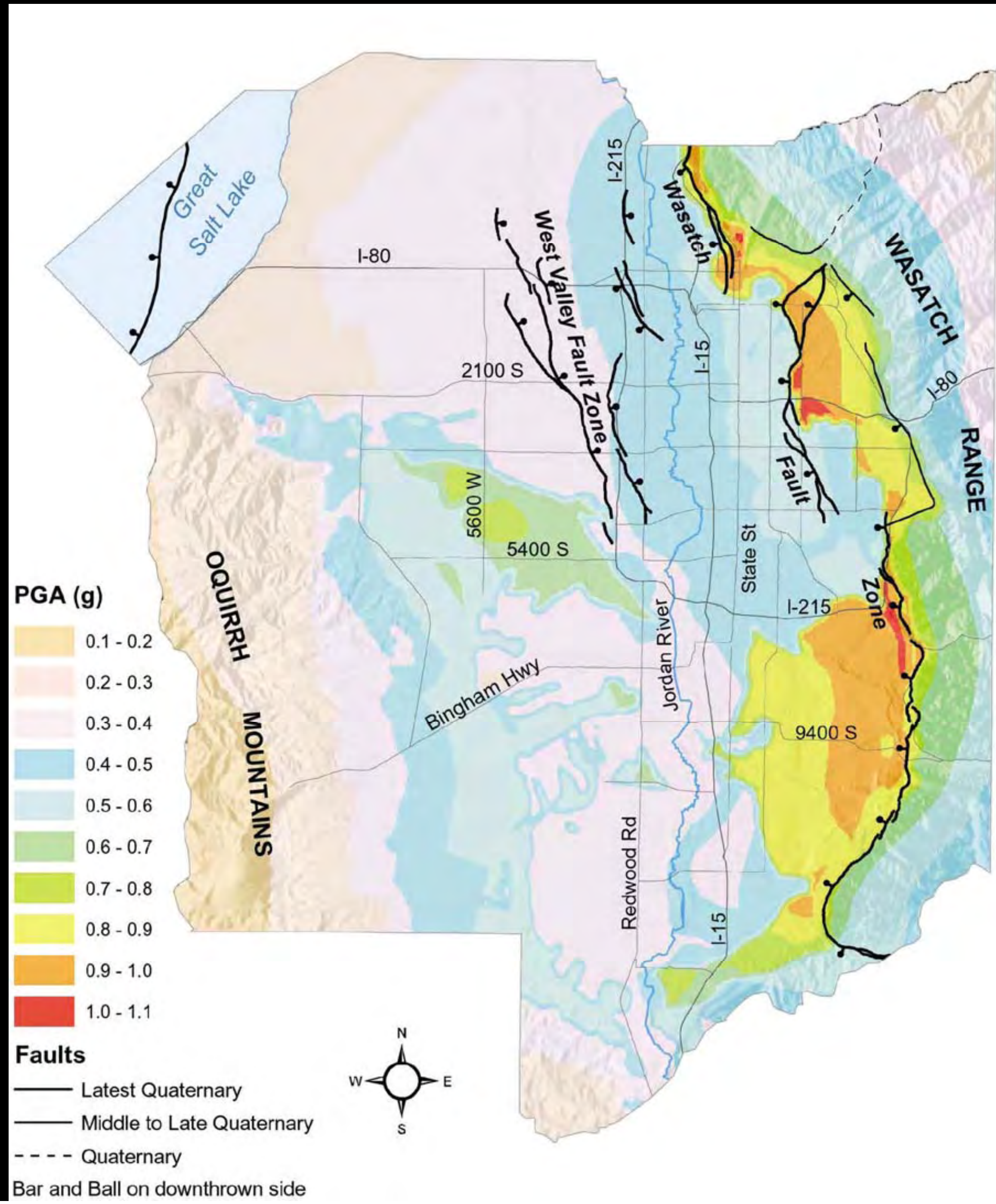
M7.0 Scenario Earthquake:

Wong et al., 2002

Probabilistic Estimates:

USGS National Strong Motion Hazard Mapping Project, Petersen et al., 2008

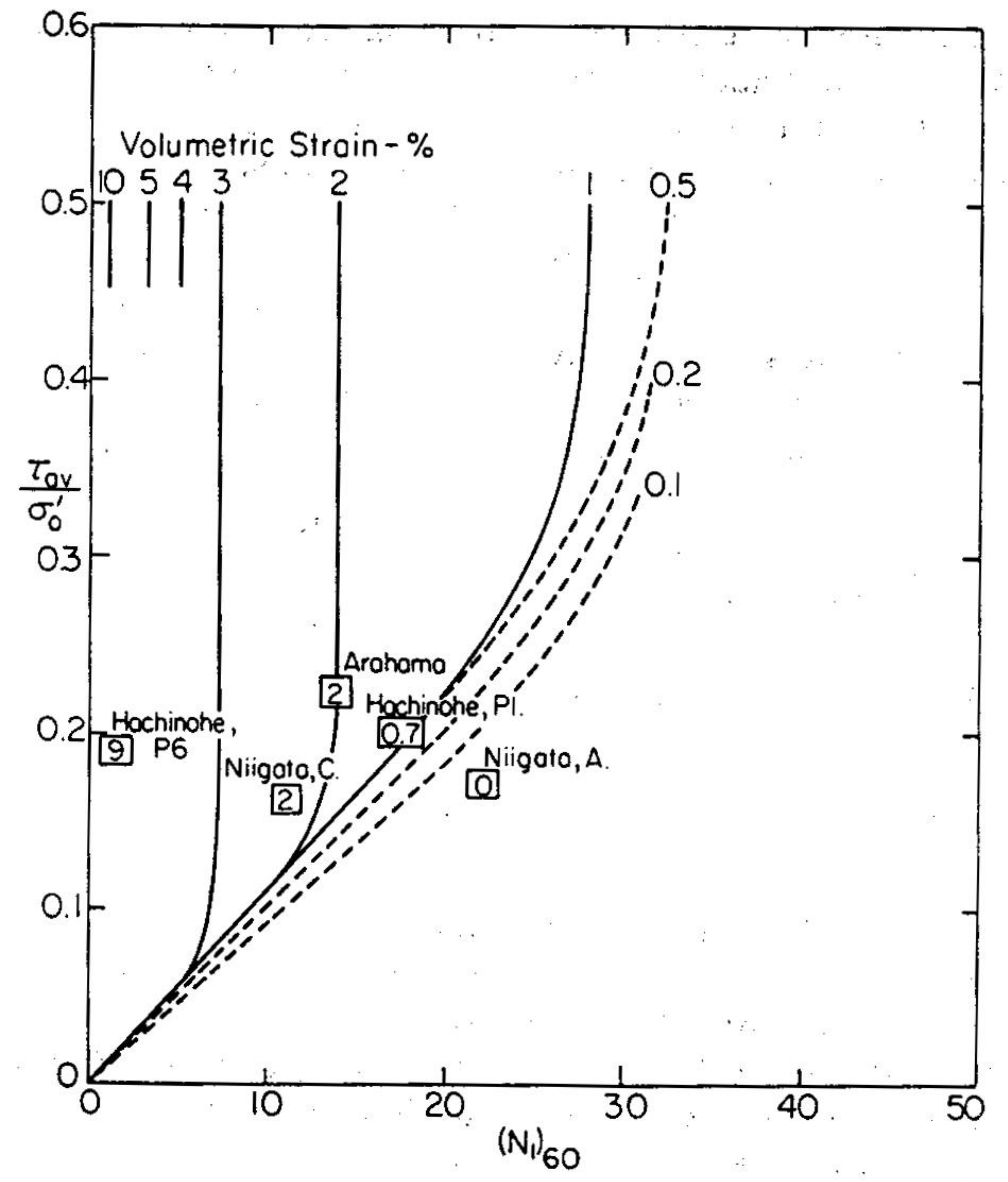
- Site-modified for V_s by Seed et al., 1997
- Deaggregations provided by Stephen Harmsen of the USGS



Map Development: Settlement Calculations

- Tokimatsu and Seed, 1987
  - Liquefaction triggering (Youd et al., 2001)
  - SPT clean sand $(N_1)_{60}$ (Youd et al., 2001)
  - Cyclic Stress Ratio (CSR)

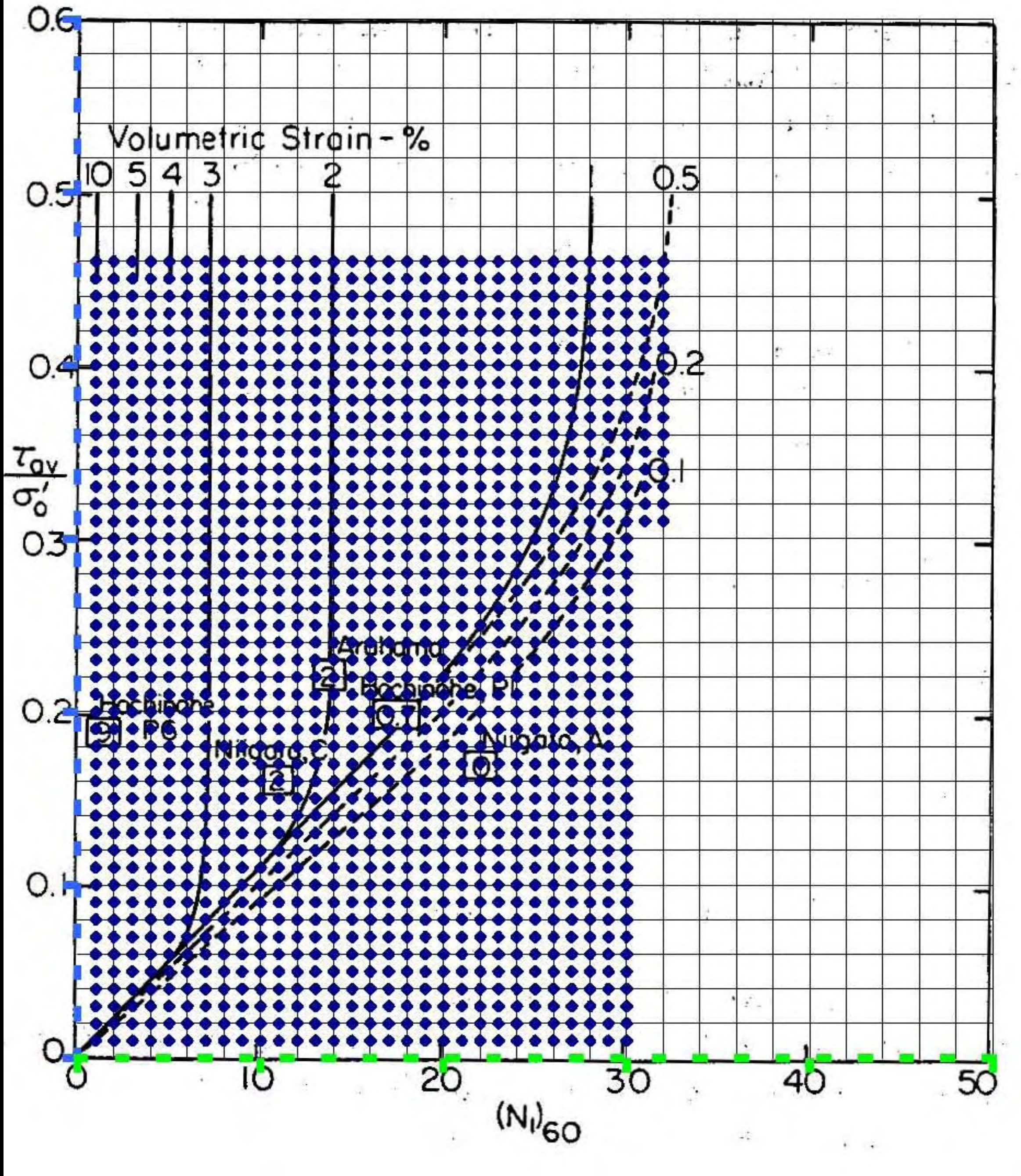
Map Development: Tokimatsu and Seed, 1987



- Liquefaction triggering (Youd et al., 2001)
- SPT clean sand $(N_1)_{60}$ (Youd et al., 2001)
- Cyclic Stress Ratio (CSR)
  - MSF from Seed et al. (1983)
- Settlements estimated where FS_{liq}<1.1

$$\frac{\tau_{av}}{\sigma_o'} = 0.65 \cdot \frac{a_{max}}{g} \cdot \frac{\sigma_o}{\sigma_o'} \cdot r_d$$

Map Development: Tokimatsu and Seed, 1987



For rapid calculations data table created with over 1,400 interpolated points

Map Development: Settlement Calculations

- Yoshimine et al., 2006
  - Ishihara and Yoshimine, 1992
    - •SPT clean sand $(N_1)_{60}$ (Youd et al., 2001)
    - •Converted to Japanese N_1 (Seed et al., 1985)
    - •Liquefaction triggering by Japanese Design Code for Highway Bridges (2000)
    - •SPT N_1 converted to D_r by Meyerhof (1957)
    - •Settlements estimated where FS_{liq}<1.1

Ishihara and Yoshimine (1992) with Yoshimine et al. (2006) inlay

$$\gamma_{max} = 3.5(2 - F_l)\frac{1 - F_{ult}}{F_l - F_{ult}} \qquad \text{if } F_{ult} \le F_l \le 2.0 \qquad (1)$$

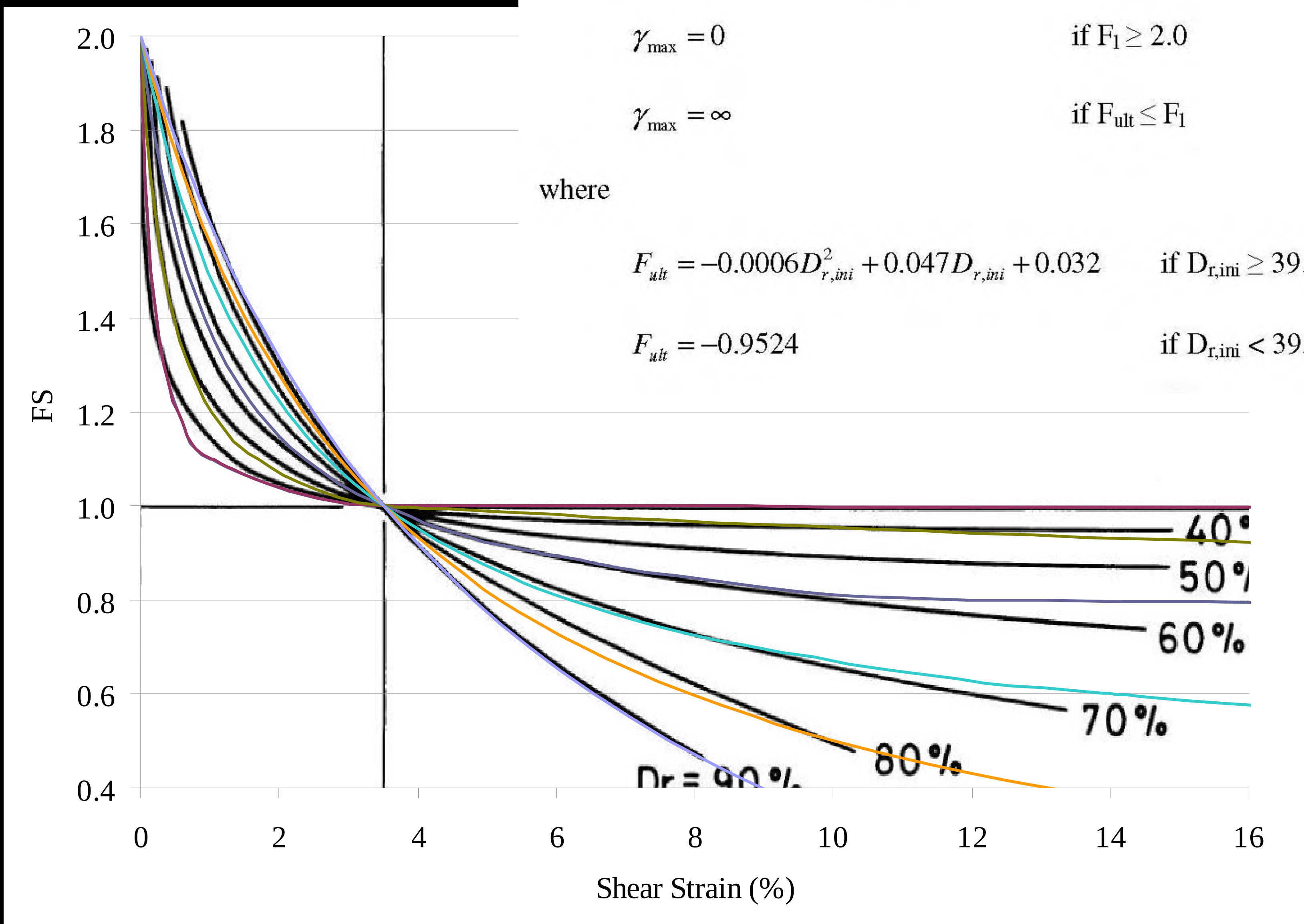
$$\gamma_{max} = 0 \qquad \text{if } F_l \ge 2.0 \qquad (2)$$

$$\gamma_{max} = \infty \qquad \text{if } F_{ult} \le F_l \qquad (3)$$

where

$$F_{ult} = -0.0006D_{r,ini}^2 + 0.047D_{r,ini} + 0.032 \qquad \text{if } D_{r,ini} \ge 39.2\% \qquad (4)$$

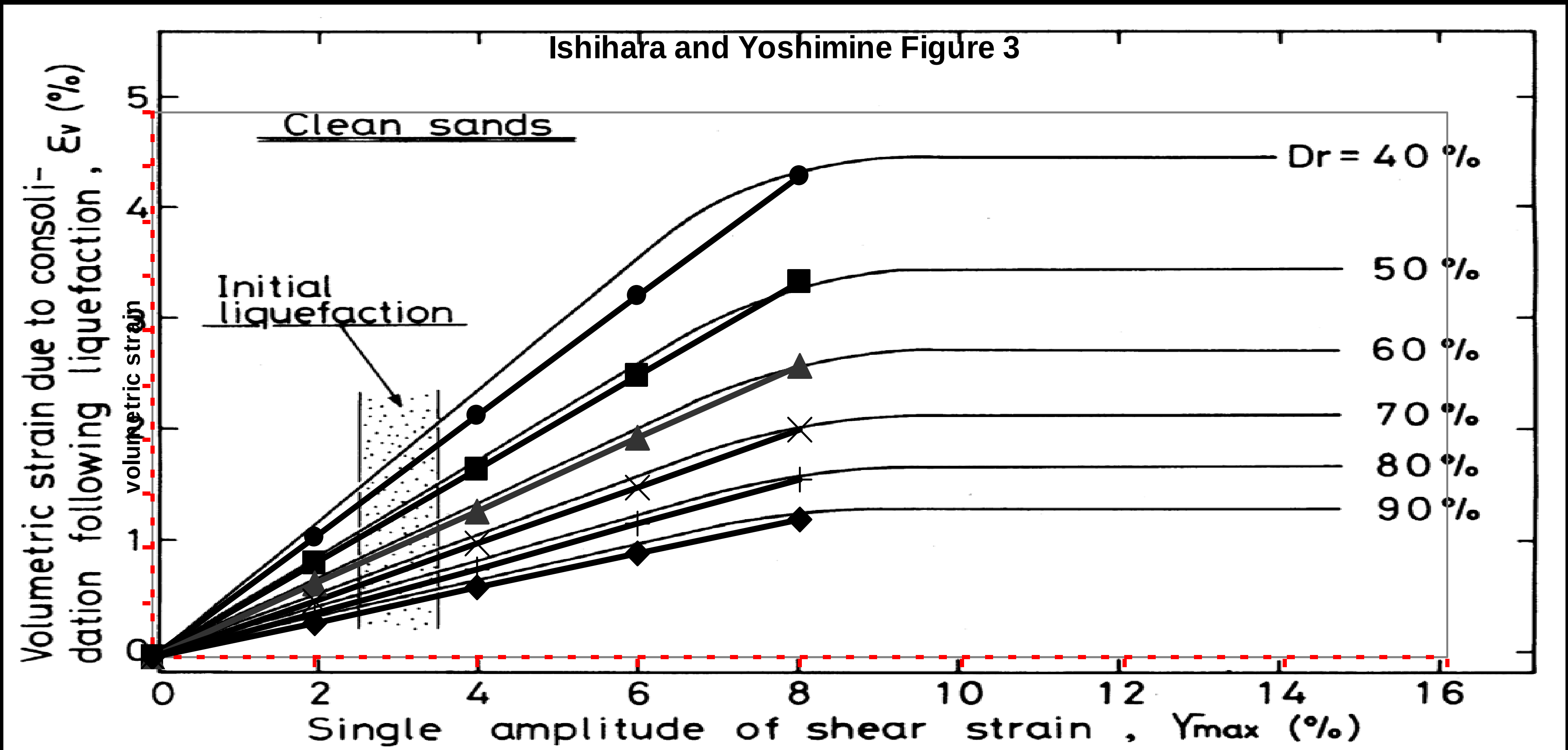
$$F_{ult} = -0.9524 \qquad \text{if } D_{r,ini} < 39.2\% \qquad (5)$$



Ishihara and Yoshimine (1992) with Yoshimine et al. (2006) inlay

$$\varepsilon_v = 1.5 e^{(-0.025 D_{r,ini})} \gamma_{max} \quad \text{if } \gamma_{max} \le 8\% \qquad (6)$$

$$\varepsilon_v = 12 e^{(-0.025 D_{r,ini})} \quad \text{if } \gamma_{max} > 8\% \qquad (7)$$



Map Development: Ground Settlement

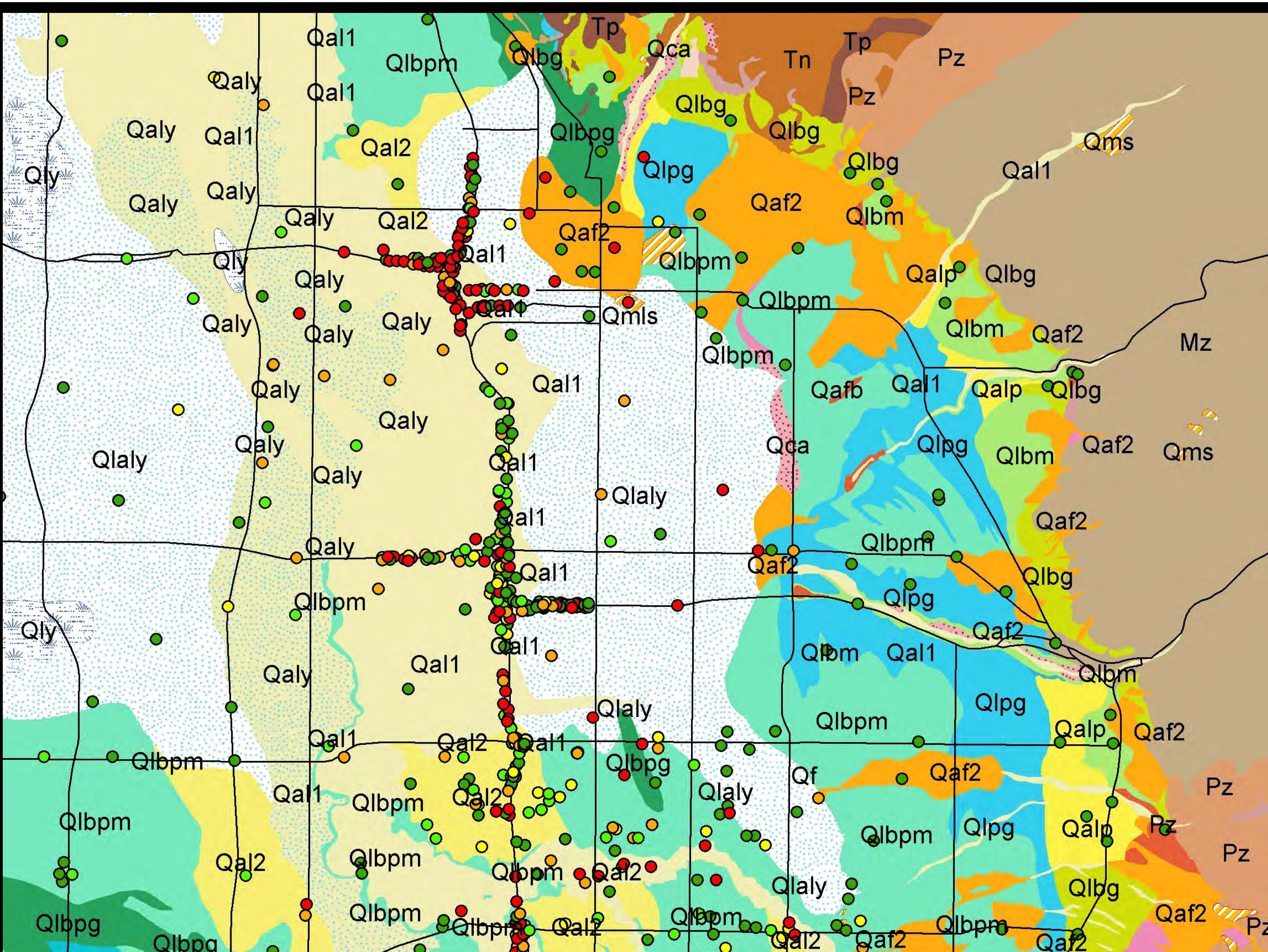
Which Method to Use?

- M7.0 Scenario Results:
  - •0.004 m Average Difference
  - •0.083 m Maximum Difference
  - •74% within 0.01 m
  - •92% within 0.025 m
  - •99% within 0.05 m
- Results “Relatively Similar” Considering Range of Input Data and End Use of Maps

Decided to Use Average of the Two Methods

Map Development: Ground Settlement

- Hazard Classes
  - Low, 0 to 0.05 m
  - Moderate, 0.05 to 0.1 m
  - High, 0.1 to 0.3 m
  - Very High, > 0.3 m
- Geologic Groupings, “Dot Map”
- M7.0 Scenario Map
  - 15% Exceedance Threshold
    - Discussed ULAG, 2009
- Probabilistic Maps
  - Mean Hazard
    - normal or log-normal?



Tp
Qal1
Qlbpm
Qlbg
Qca
Tn
Tp
Pz
Qaly
Qal1
Pz
Qlbg
Qaly
Qal1
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Qlbpg
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Qaf2
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Qaly
Qal2
Qaf2
Qal1
Qly
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Qaly
Qalp
Qlbg
Qlbpm
Qal1
Qmls
Qaly
Qaly
Qaly
Qlbm
Qaf2
Mz
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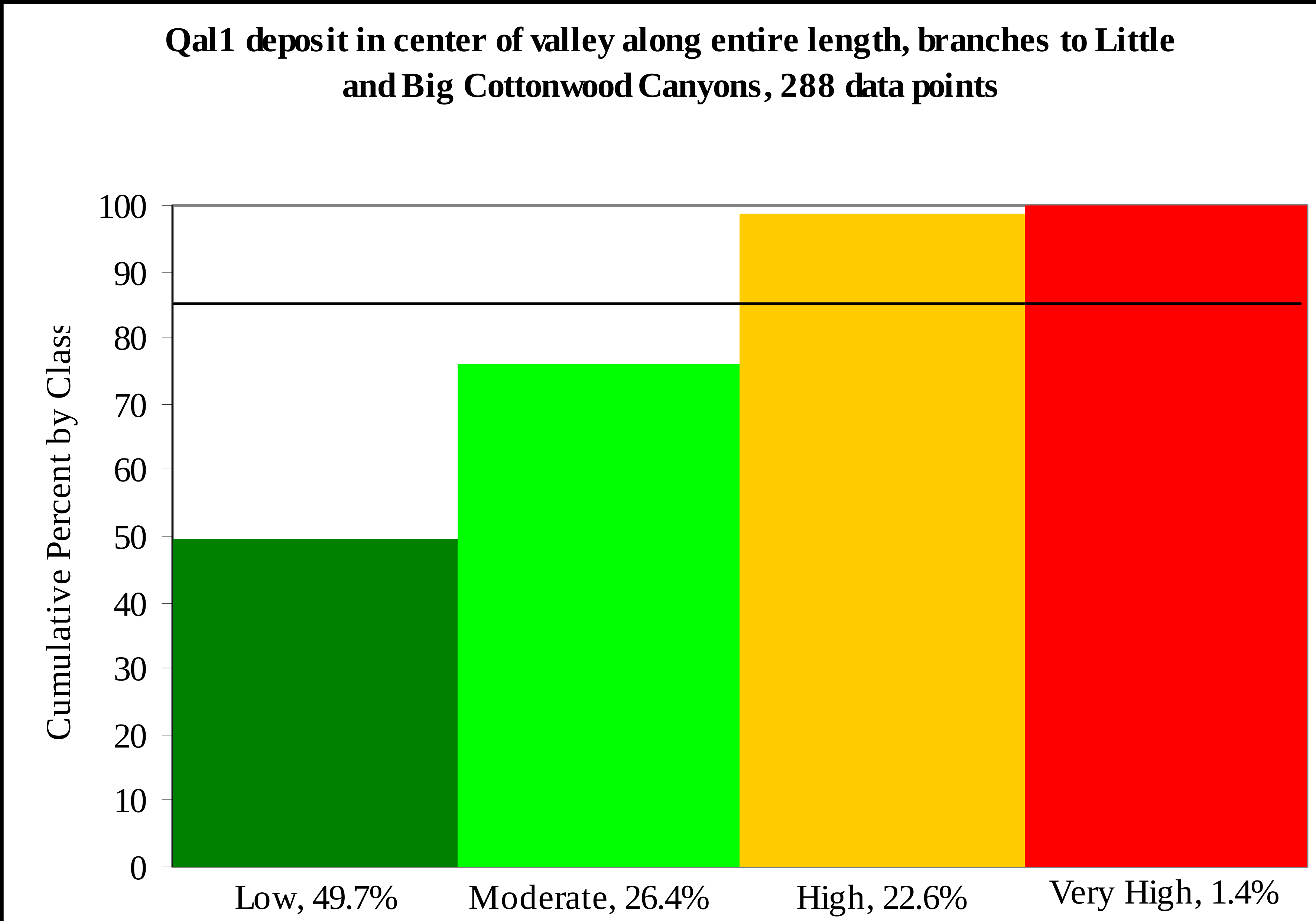
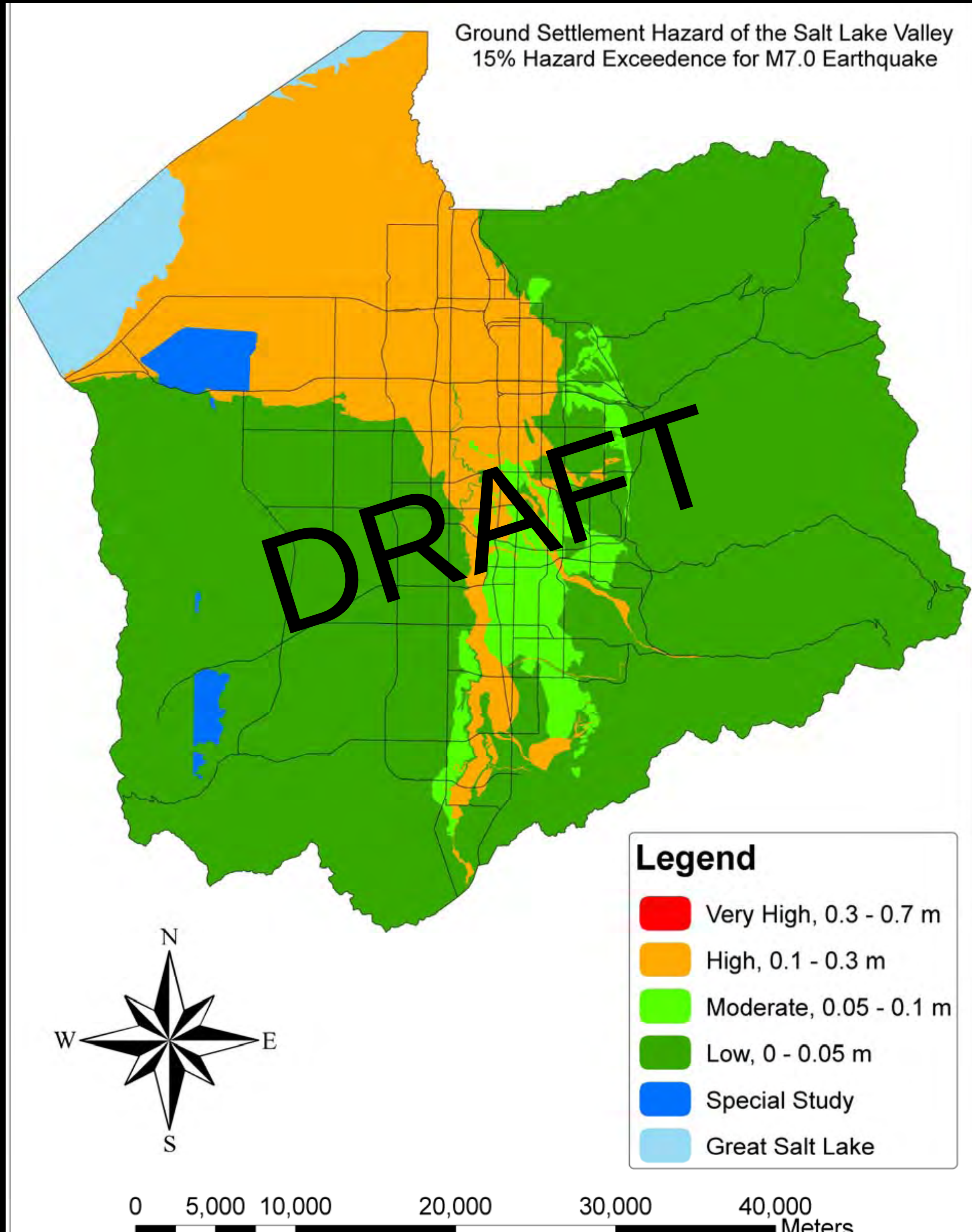
Qaf2
Pz

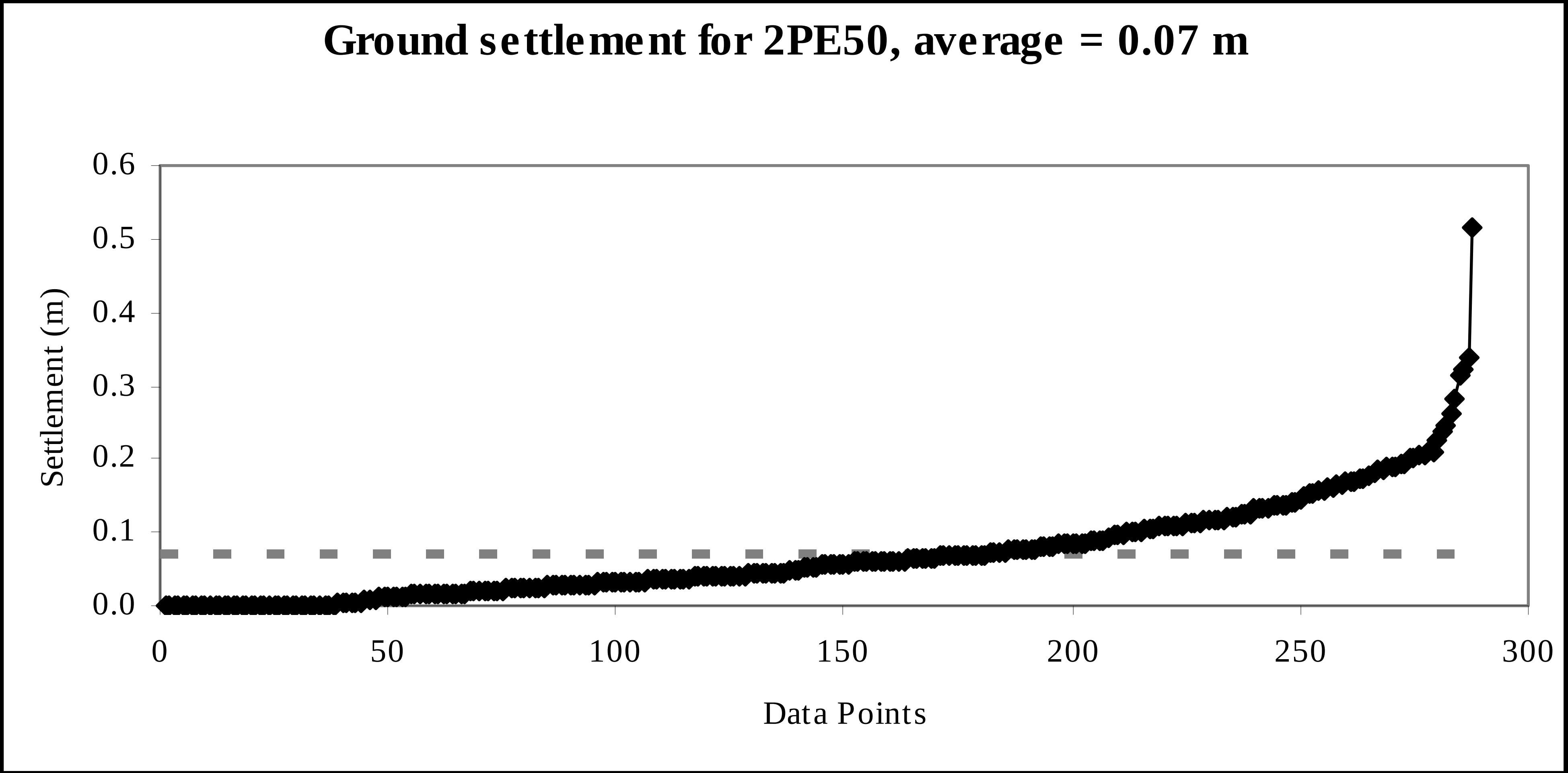
Map Development: Ground Settlement



M7.0 Wasatch Fault Averaged Settlement


Ground Settlement Hazard of the Salt Lake Valley
15% Hazard Exceedence for M7.0 Earthquake
DRAFT
Legend
Very High, 0.3 - 0.7 m
High, 0.1 - 0.3 m
Moderate, 0.05 - 0.1 m
Low, 0 - 0.05 m
Special Study
Great Salt Lake
N
W
E
S
0
5,000
10,000
20,000
30,000
40,000
Meters

Map Development: Ground Settlement



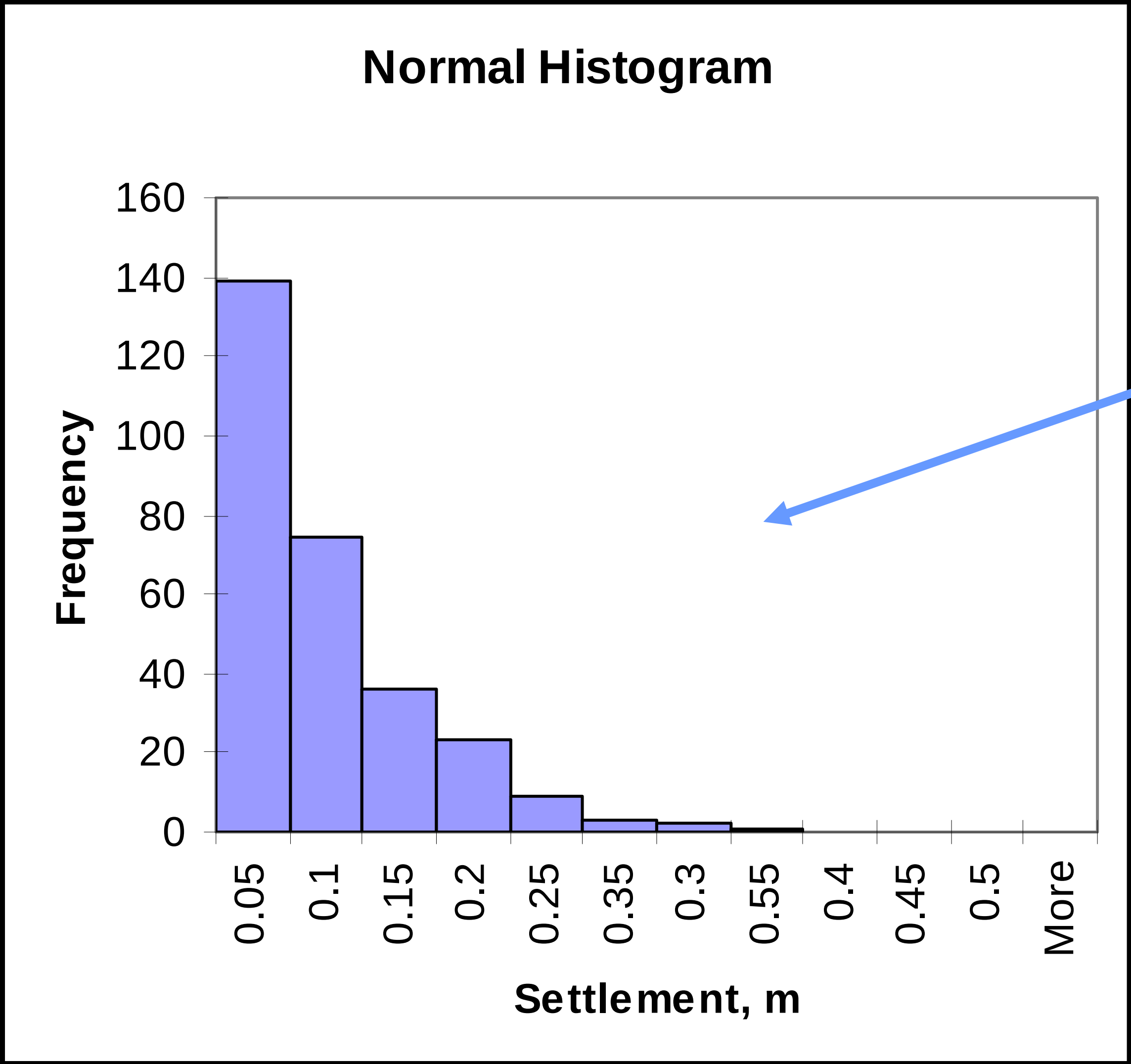
2PE50 Averaged Settlement

Arithmetic Mean

Map Development: Ground Settlement

2PE50 Averaged Settlement

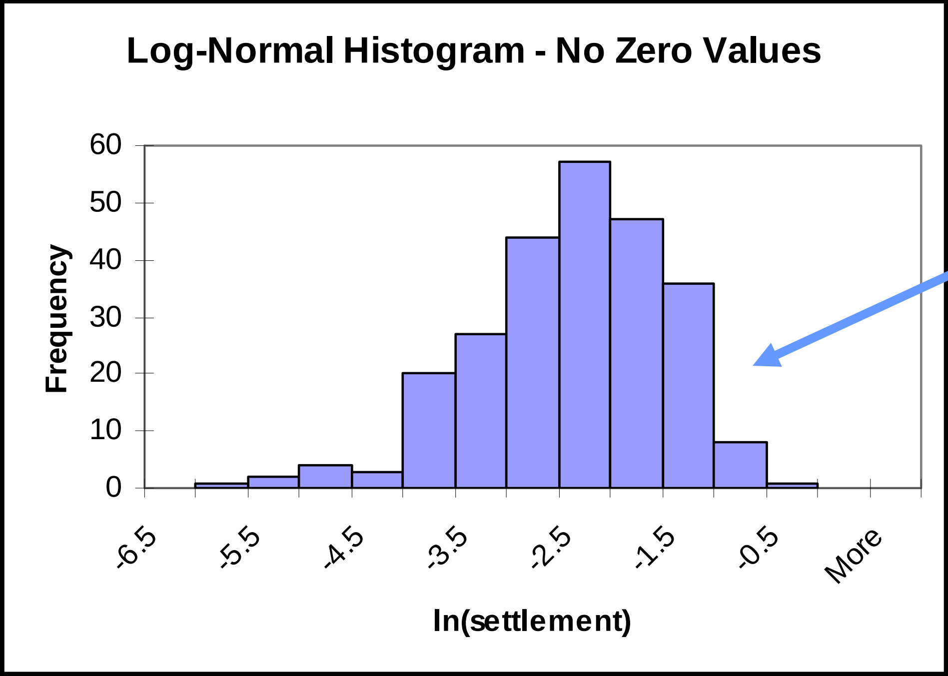
Normal or Log-Normal?



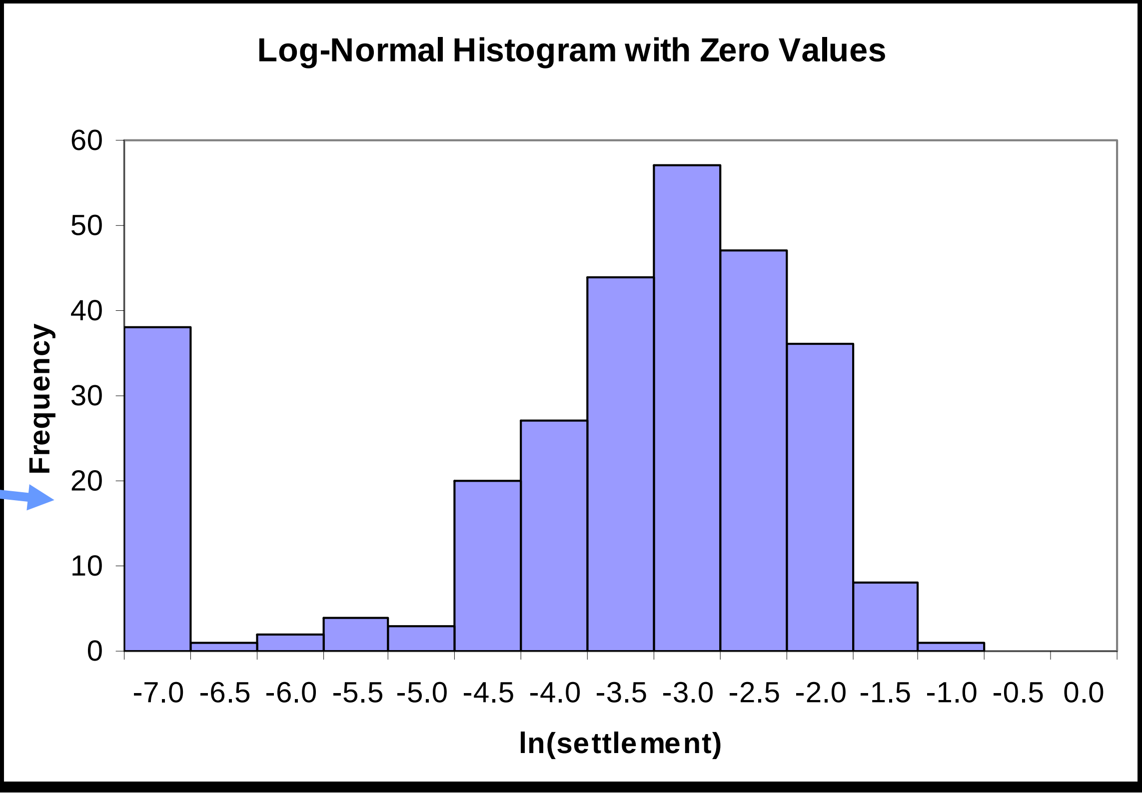
0.066 m Average Settlement

Map Development: Ground Settlement

2PE50 Averaged Settlement

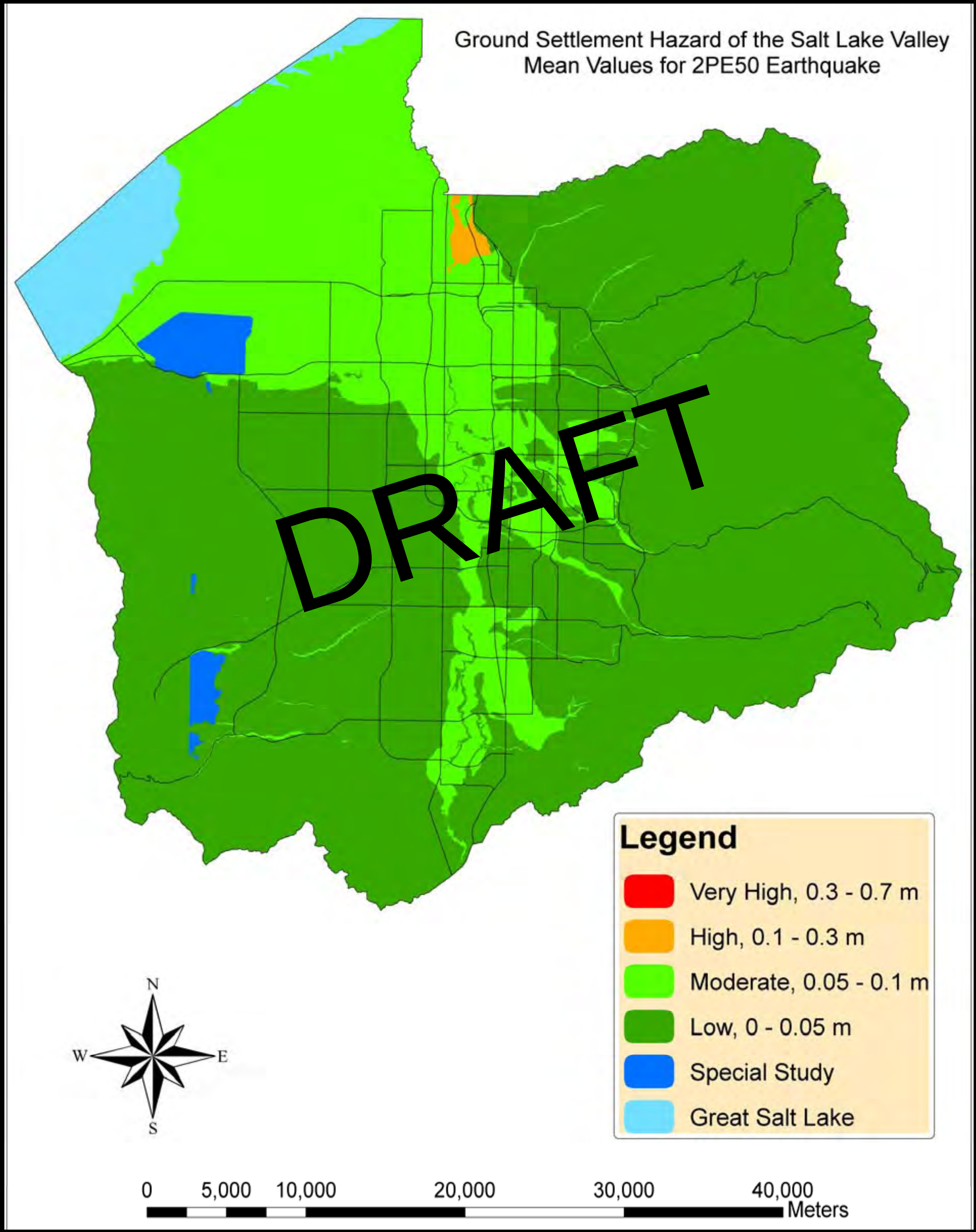


0.057 m Log-Transformed Averaged Settlement

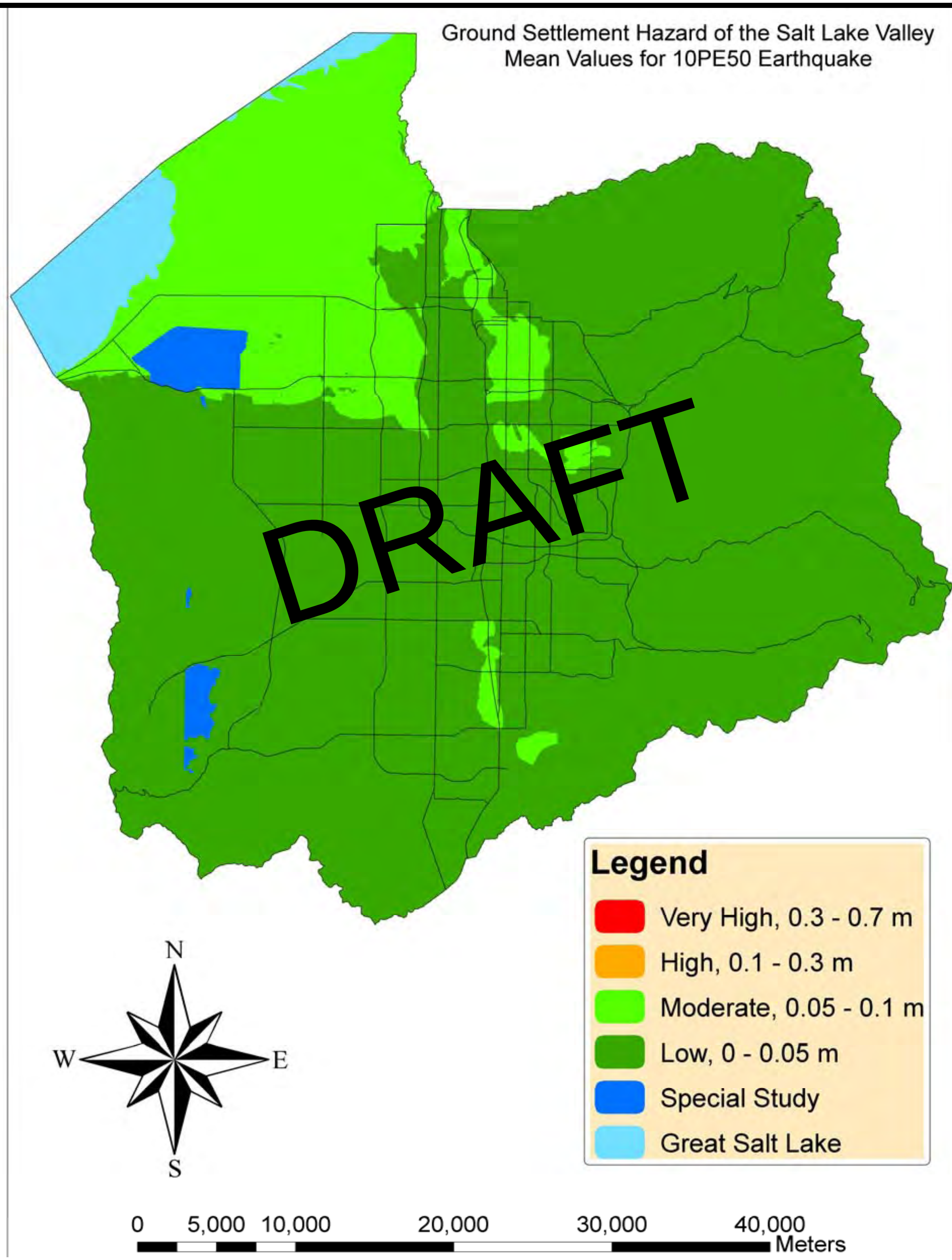


0.033 m Log-Transformed Averaged Settlement

Zero-values assigned insignificant settlement value of 0.001 m



Ground Settlement Hazard of the Salt Lake Valley
Mean Values for 2PE50 Earthquake
DRAFT
Legend
Very High, 0.3 - 0.7 m
High, 0.1 - 0.3 m
Moderate, 0.05 - 0.1 m
Low, 0 - 0.05 m
Special Study
Great Salt Lake
N
W
E
S
0
5,000
10,000
20,000
30,000
40,000
Meters


Ground Settlement Hazard of the Salt Lake Valley
Mean Values for 10PE50 Earthquake
DRAFT
Legend
Very High, 0.3 - 0.7 m
High, 0.1 - 0.3 m
Moderate, 0.05 - 0.1 m
Low, 0 - 0.05 m
Special Study
Great Salt Lake
N
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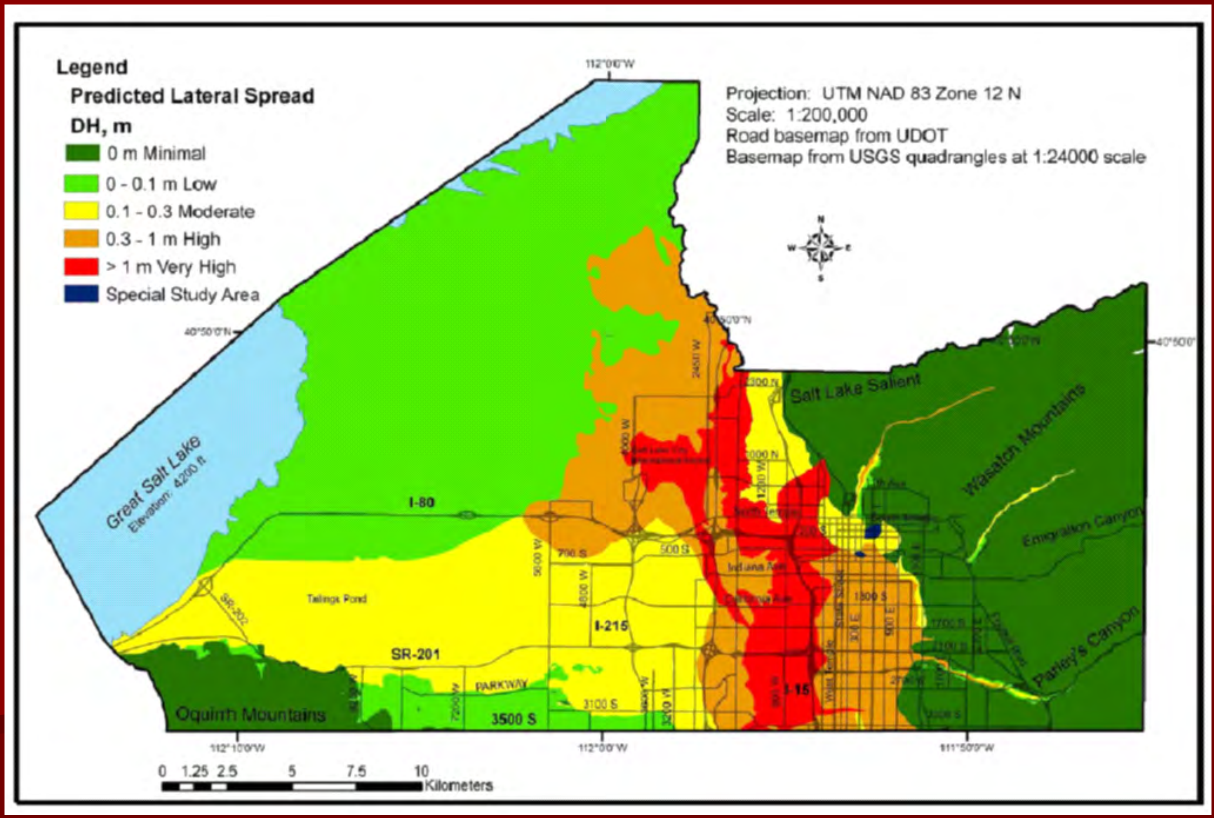
W
0
5,000
10,000
20,000
30,000
40,000
Meters

Acknowledgments

- USGS National Earthquake Hazards Reduction Program (NEHERP Award 04HQGR0026)
- Stephen Harmsen
- Michael Olsen
- Utah Liquefaction Advisory Group (ULAG)
- Utah Department of Transportation (UDOT)
- Municipalities in the Salt Lake Valley

Questions?

MAPPING AND UNCERTAINTY ANALYSIS OF LIQUEFACTION-INDUCED LATERAL SPREAD DISPLACEMENTS FOR GEOTECHNICALLY UNDER-SAMPLED GEOLOGIC UNITS



A Research Proposal

By: Daniel T. Gillins

Contents

- Introduction
- Current Mapping Efforts in Utah
- Problem Definition
- Proposed Research Program
- Conclusion

Introduction

- Areas of Utah's urban corridor contain loose sand deposits that are susceptible to liquefaction during major earthquakes
- It is important to quantify and map areas of potential ground displacement so that these locales can be carefully considered during land use planning and engineering design
- Current mapping techniques require large quantities of geotechnical data
- Many areas in Utah lack sufficient quantities of geotechnical data

Current Mapping Efforts in Utah

- Current lateral spread hazard mapping efforts in Utah use the Bartlett & Youd models (Olsen et al. [2007], Erickson et al. [2008])
- Bartlett & Youd empirical models require dense spatial clusters of borehole data
- Large quantities of borehole data from SPT and CPT are available in Salt Lake County

The Bartlett & Youd Model

- Combines ideas of the LSI and Hamada models
  - Includes topographic, seismic, and geotechnical parameters
- Empirical model most recently updated by Youd et al. (2002)
- Based on multi-linear regression of a large database of lateral spreading case studies

The Bartlett & Youd Model (continued)

- Definition of terms—
  - M = Moment magnitude of an earthquake
  - R = distance from point of interest to seismic energy source
  - W = ratio of height of free face to distance from free face to point of interest
  - S = ground slope (%)
  - T_{15} = thickness of liquefiable layer (saturated sand with $(N_1)_{60} < 15$)
  - F_{15} = fines content of the T_{15} layer
  - $D50_{15}$ = mean grain size of the T_{15} layer

The Bartlett & Youd Model (continued)

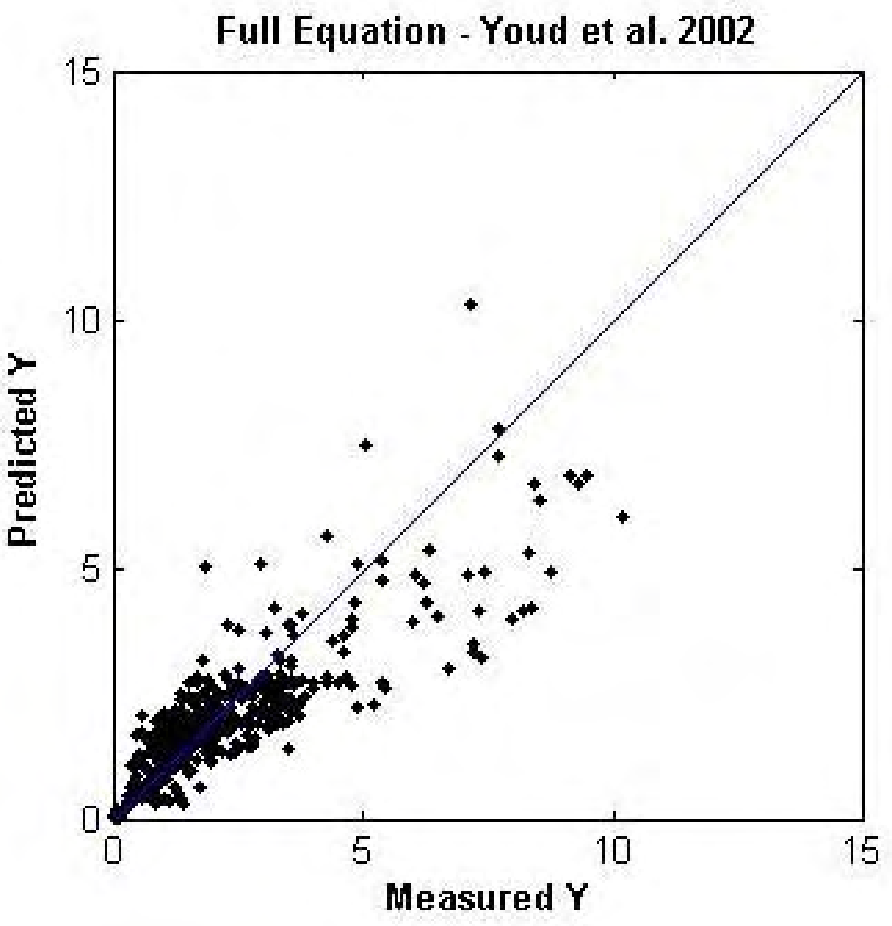
- For sites near steep banks, the *free-faced model* is:

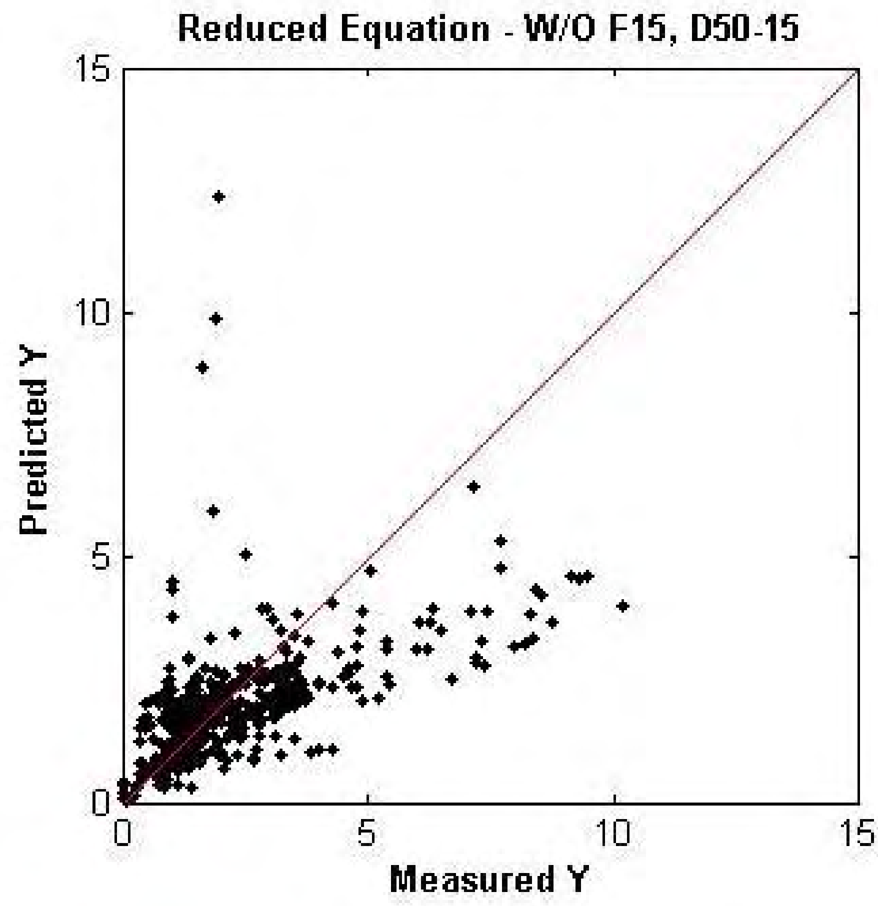
$$\log D_H = -16.713 + 1.532\, M - 1.406 \log R^* - 0.012\, R + 0.592 \log W + 0.540 \log T_{15} + 3.413 \log (100 - F_{15}) - 0.795 \log (D50_{15} + 0.1 \text{ mm})$$

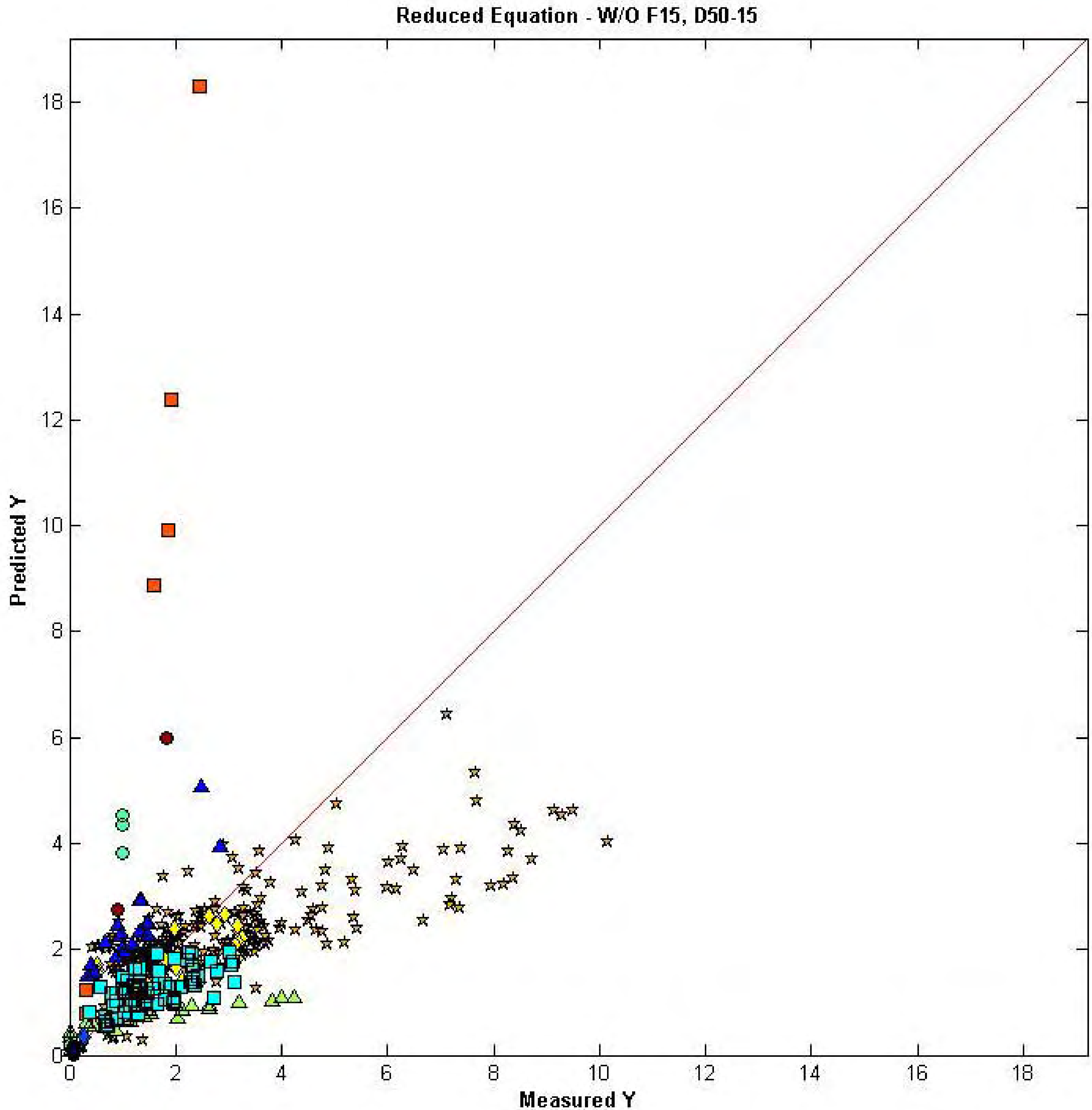
- For gently sloping ground, the *ground-slope model* is:

$$\log D_H = -16.213 + 1.532\, M - 1.406 \log R^* - 0.012\, R + 0.338 \log S + 0.540 \log T_{15} + 3.413 \log (100 - F_{15}) - 0.795 \log (D50_{15} + 0.1 \text{ mm})$$

Remove the FC and D50 terms?

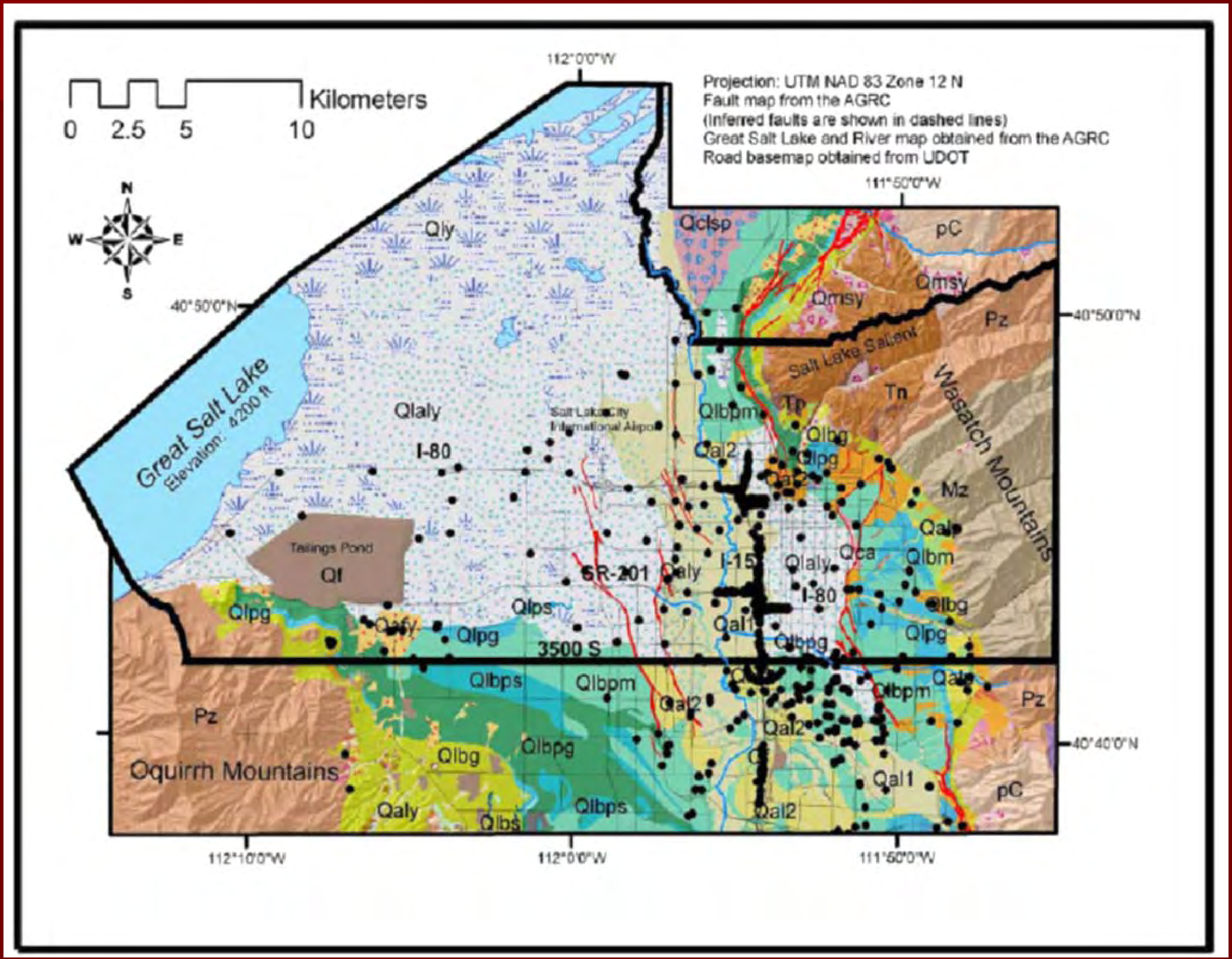






Reduced Equation - W/O F15, D50-15
Predicted Y
Measured Y
0
2
4
6
8
10
12
14
16
18

SPT Locations with Surficial Geologic Base Map for Northern Salt Lake County (Olsen et al. [2007])



The Dot Map

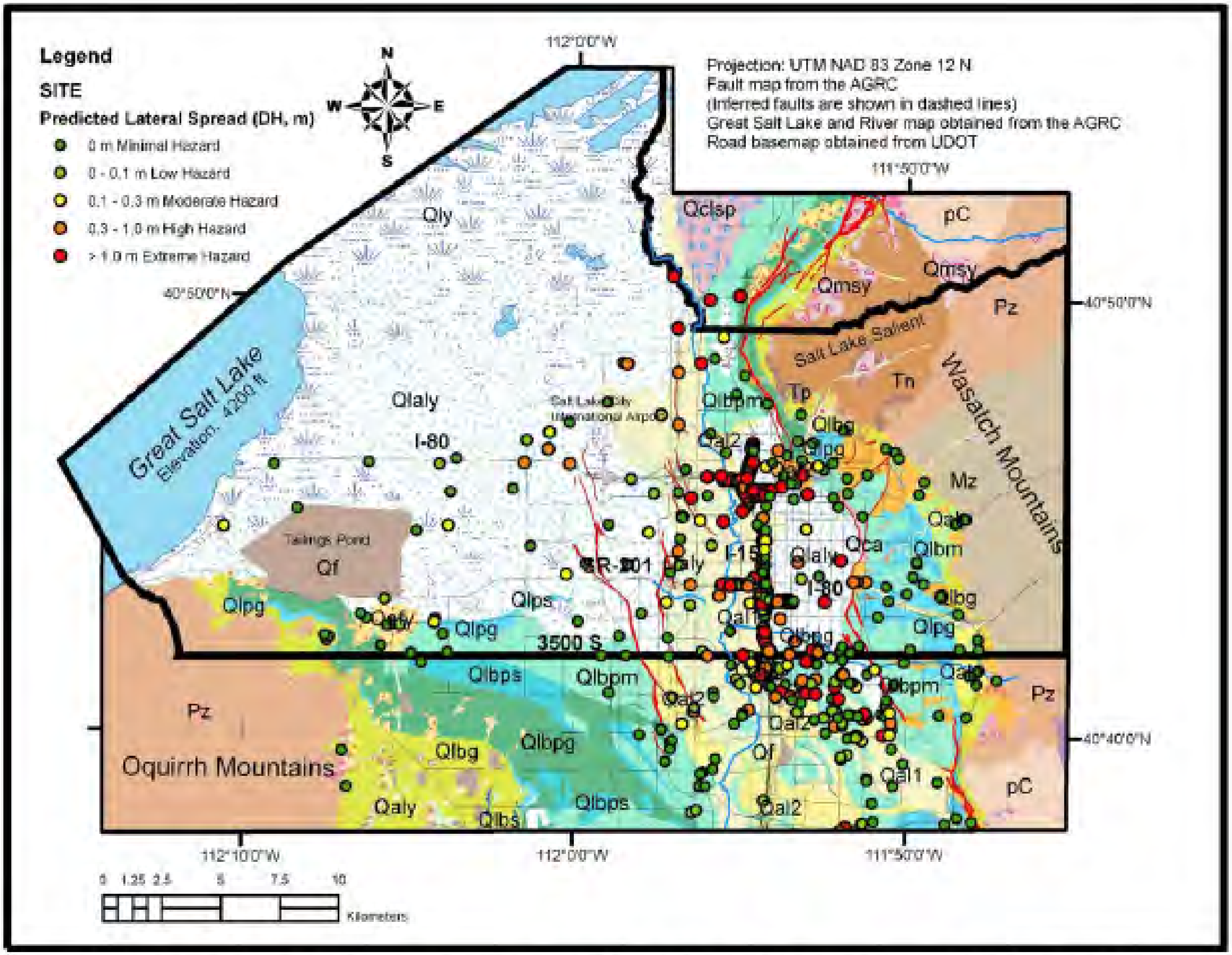
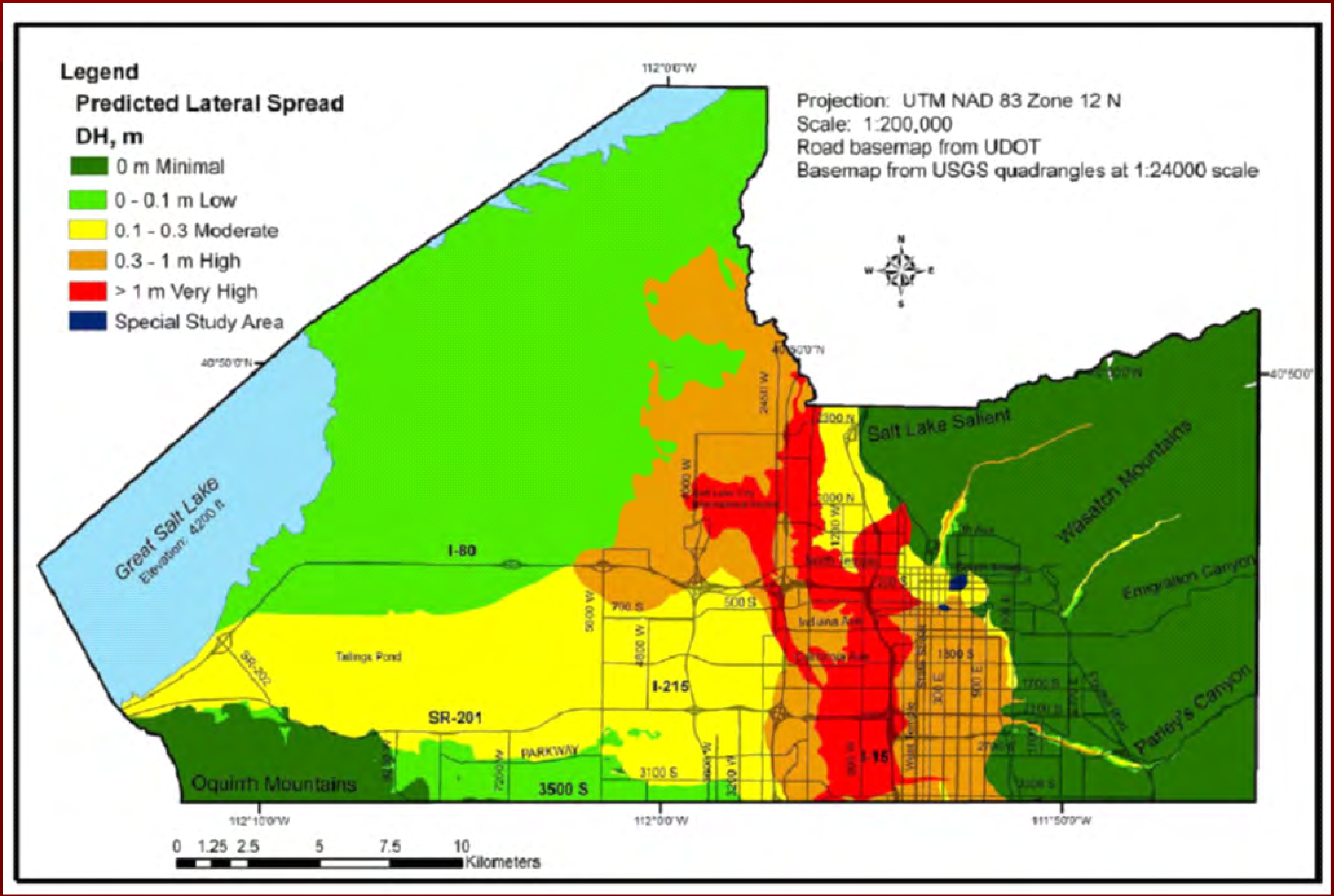


Figure 15 - Predicted lateral spread displacements underlain by a surficial geologic map for the Salt Lake Valley (modified from Personious and Scott (1992), Biek et al. (2004), and Miller (1980))

Lateral Spreading Hazard Map for Northern Salt Lake County Based on a Magnitude 7.0 Earthquake (from Olsen et al. [2007])



Problem Definition

- What is one to do to when lacking dense quantities of site-specific geotechnical data?
- Davis, Weber, Utah, Box Elder and Cache counties lack dense clusters of geotechnical borehole investigations
- Current mapping efforts in Utah cannot be continued without a new methodology
- Current mapping methods that use estimates of lateral spread at each borehole have uncertainty

The Key Premises

1. Comprehensive empirical models are generally preferred to reduced models even if some factors used in the comprehensive models are less certain or estimated.
2. Geotechnical factors can be reasonably estimated for a particular depositional environment and/or soil type and the uncertainty of these estimates can be quantified.

Proposed Research Tasks

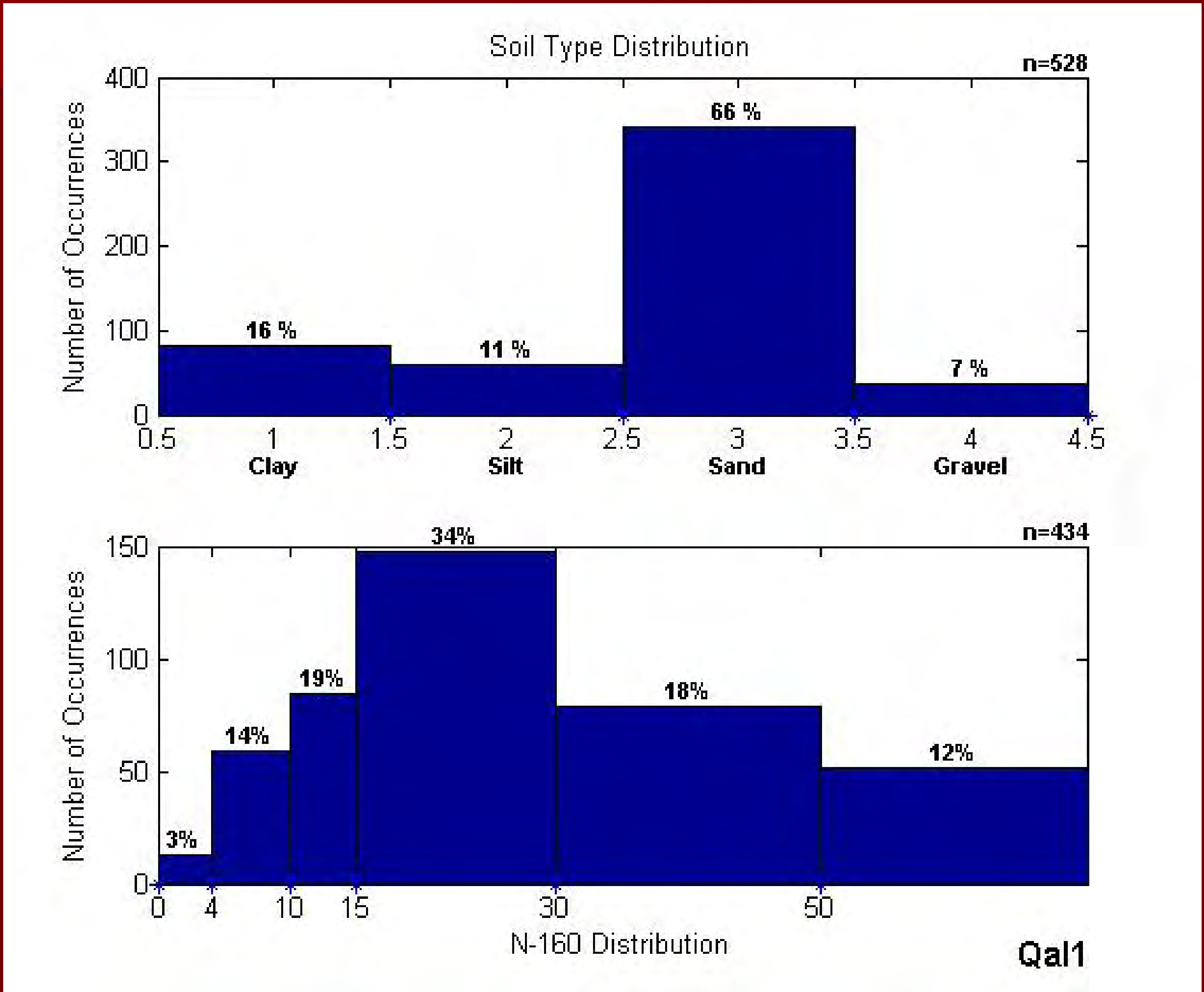
1. Develop Modified Regression Models
   – (1) reduce the model to a smaller set of factors that are supported by the data
     - Possibly use soil descriptions from borehole logs

   – (2) maintain the full model, but estimate the missing factors via correlations or inferred data

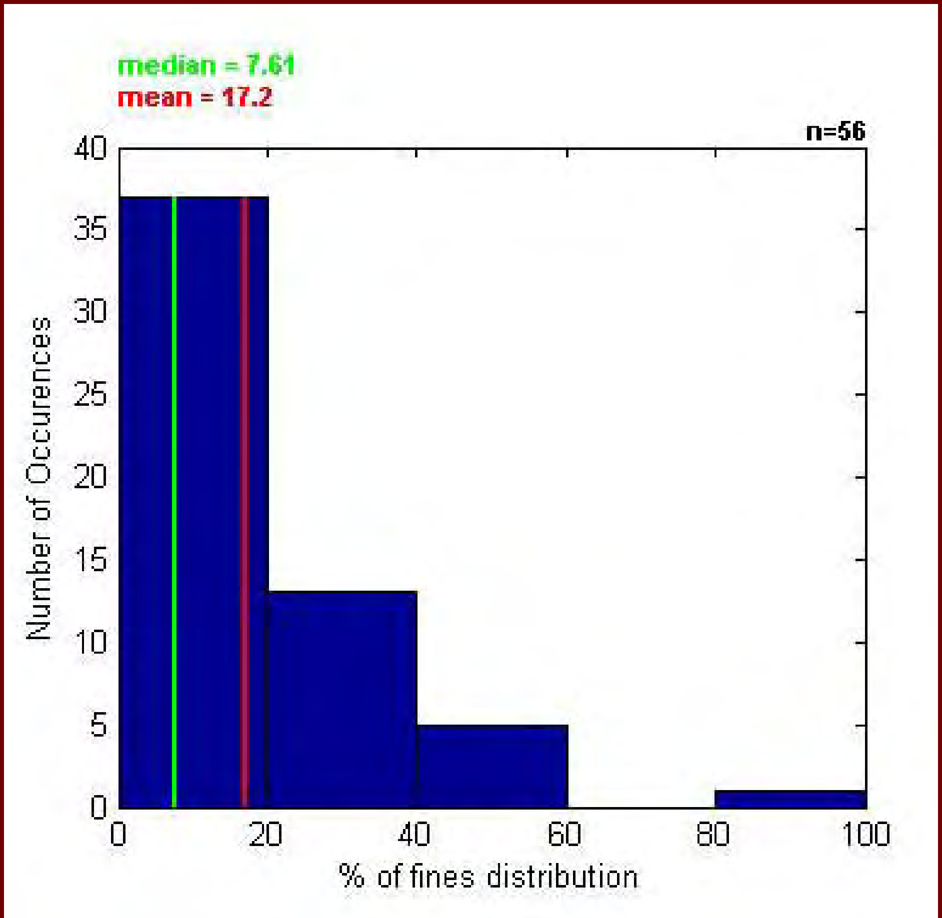
Proposed Research Tasks (continued)

2. Correlation and Variability Analysis of Geotechnical Properties for Mapped Geological Units in the Salt Lake
   - Using these correlations, it may be possible to infer the geotechnical properties of an under sampled zone based solely on its mapped geological unit description using data obtained from the same or similar type of geologic unit

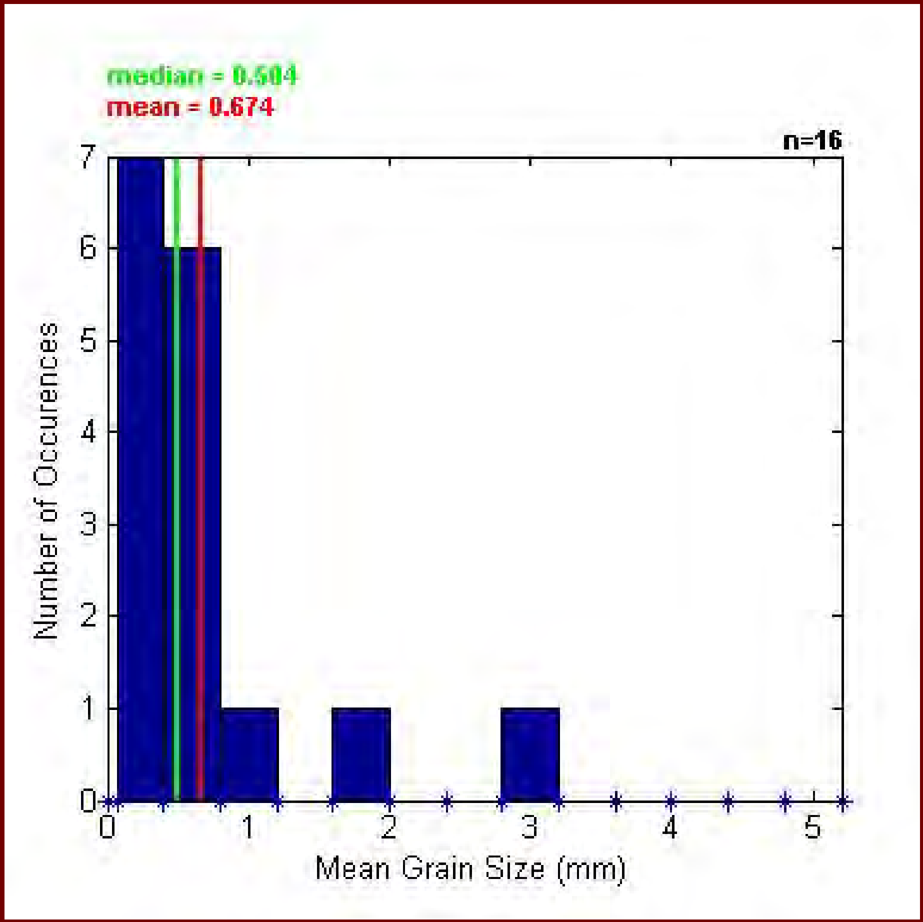
The Qal1 Unit



Qal1 - Sand



median = 7.61
mean = 17.2
n=56
Number of Occurences
% of fines distribution
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100



median = 0.504
mean = 0.674
n=16
Number of Occurences
Mean Grain Size (mm)
0
1
2
3
4
5
6
7
0
1
2
3
4
5

Proposed Research Tasks (continued)

3 . Discrimination Analysis of Geologic Units Based on Geotechnical Properties

1. How different or similar are the geologic units as judged by their geotechnical properties?
2. Can the depositional environment framework of Youd and Perkins (1978) be used as a basis of classifying and grouping similar geologic units?
3. What is the typical variation of geotechnical properties within a given unit?
4. Can similar geologic units be pooled or grouped together to improve the robustness of the sampling and estimation of variation?

Susceptibility of Sedimentary Deposits to Liquefaction (from Youd & Perkins [1978])

Type of Deposit	General Distribution of Cohesionless sediments in deposits	Likelihood that Cohesionless Sediments, When Saturated, Would be Susceptible to Liquefaction (by Age of Deposit			
		<500 yr	Holocene	Pleistocene	Pre-Pleistocene
(1)	(2)	(3)	(4)	(5)	(6)
(a) Continental Deposits					
River Channel	Locally Variable	Very High	High	Low	Very Low
Flood Plain	Locally Variable	High	Moderate	Low	Very Low
Alluvial Fan and Plain	Widespread	Moderate	Low	Low	Very Low
Marine Terraces and Plains	Widespread	-----	Low	Very Low	Very Low
Delta and Fan-delta	Widespread	High	Moderate	Low	Very Low
Lacrustine and Playa	Variable	High	Moderate	Low	Very Low
Colluvium	Variable	High	Moderate	Low	Very Low
Talus	Widespread	Low	Low	Very Low	Very Low
Dunes	Widespread	High	Moderate	Low	Very Low
Loess	Variable	High	High	High	Unknown
Glacial Till	Variable	Low	Low	Very Low	Very Low
Tuft	Rare	Low	Low	Very Low	Very Low
Tephra	Widespread	High	High	?	?
Residual Soils	Rare	Low	Low	Very Low	Very Low
Sebka	Locally Variable	High	Moderate	Low	Very Low

Proposed Research Tasks (continued)

4. Develop a Weighting Scheme for Interpolation of Lateral Spread Estimates

– Estimates of lateral spread displacement will be interpolated to a uniform grid

– Highest weights will be assigned to the best quality data and/or its proximity to the data point

Proposed Research Tasks (continued)

5. Uncertainty Analysis
   - Aleatory Uncertainty - arises because of natural variation in the performance of the system
     - Even well-characterized geologic units have this type
     - Quantify through correlations and analysis in Tasks 2 and 3
   - Epistemic Uncertainty - a lack of knowledge about the behavior of the system that is conceptually resolvable
     - The natural variability of geotechnical properties where the corresponding unit has been poorly characterized
     - Uncertainty not fully described in the regression model
     - Quantify through Monte Carlos Techniques

Proposed Research Tasks (continued)

6. Develop the Mapping Procedure
   – Determine how to handle patterns in the predictions of lateral spread at the gridded points in order to produce a regional map

7. Implement the Mapping Procedure and Validate
   – Map an under-sampled area outside of Salt Lake County & validate with site-specific data

Conclusion

- Current models in predicting and mapping liquefaction-induced lateral displacements require dense clusters of geotechnical data
- A new methodology must be developed to predict lateral displacements in areas lacking sufficient geotechnical data to further mapping efforts
  - Uncertainty will be quantified
  - Real-time lateral spreading hazard maps can be developed in the future

Questions?