Bedrock Depths and Relation to Site Amplification

Update on St. Louis Area Earthquake Hazard Mapping Project

Tuesday April 29, 2008

St Louis, Missouri

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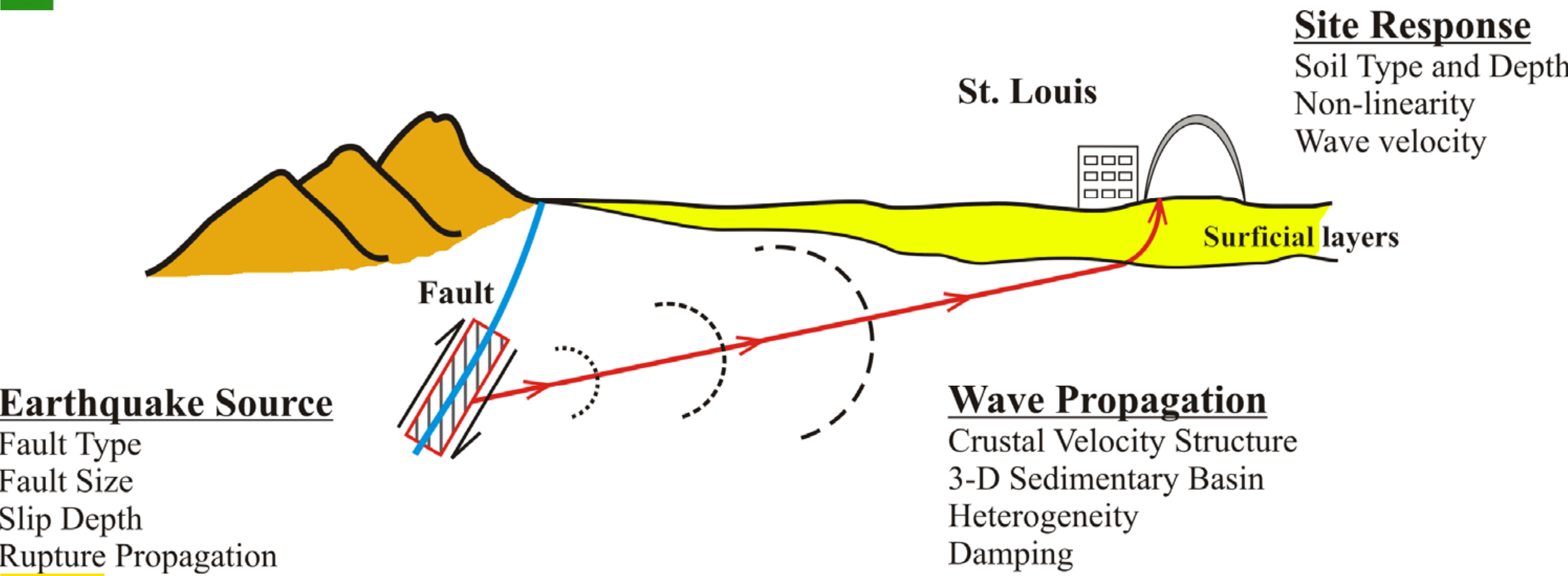
Missouri University of Science & Technology

MISSOURI S&T University of Science & Technology

Seismic Hazard Analysis Requires an appreciation of three effects:

- Source, Path, and Site Effects



Construction of a Virtual Geotechnical Database for the Geology Underlying the St. Louis Metropolitan Area

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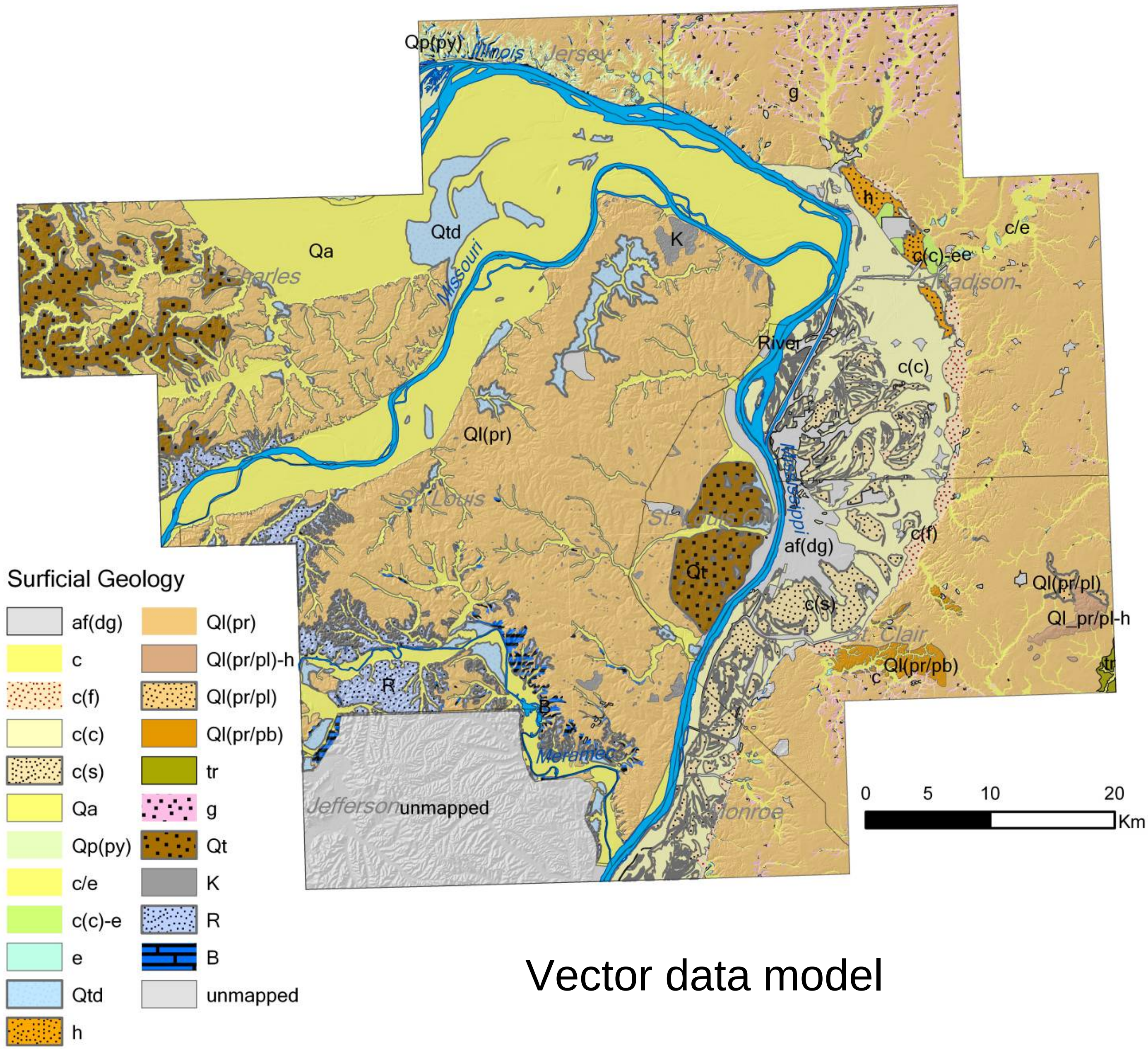
Seven GIS Geodata layers underlying the *St. Louis Metro Area*

- We collected and/or estimated the following information:
  - **1) Surficial geology**
  - **2) Loess thickness**
  - **3) Bedrock geology**
  - **4) Borehole information**
  - **5) Shear wave velocities of surficial materials**
  - **6) Depth to groundwater**
  - **7) Depth to Paleozoic age bedrock**
- Goal is to estimate the severity of shaking:
  - Amplification of incoming seismic energy due to soil cap overlying dense Paleozoic age bedrock
  - Magnification of incoming seismic energy due to impedance contrast with the soil cap

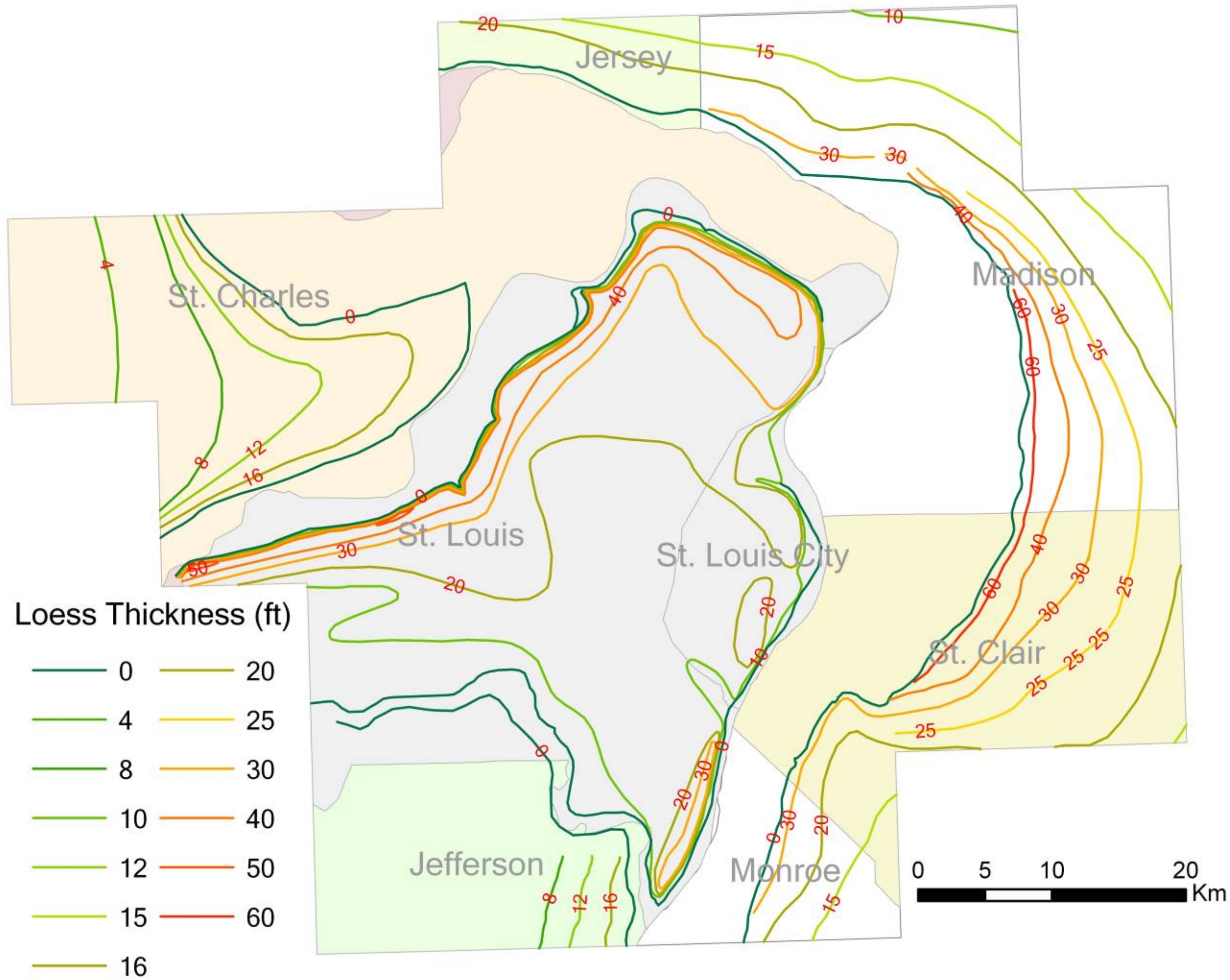
Compiled Surficial Geologic Map



Vector data model

Loess Thickness Map (in feet)

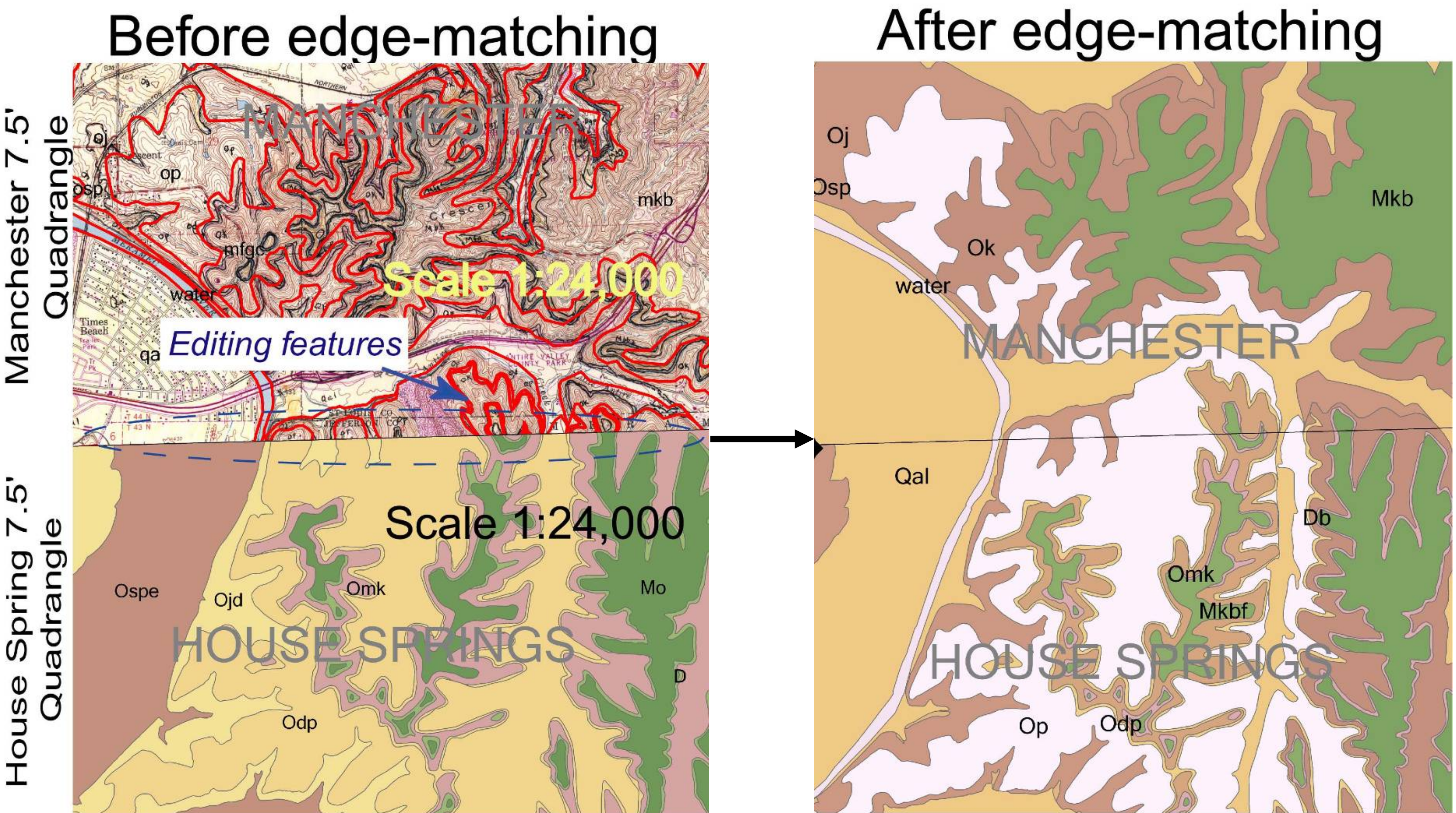
- Loess (Peoria and Roxana Silts):
  - Thickest along the river bluffs bordering the Missouri and Mississippi Rivers; and
  - Thins exponentially, away from the river bluffs



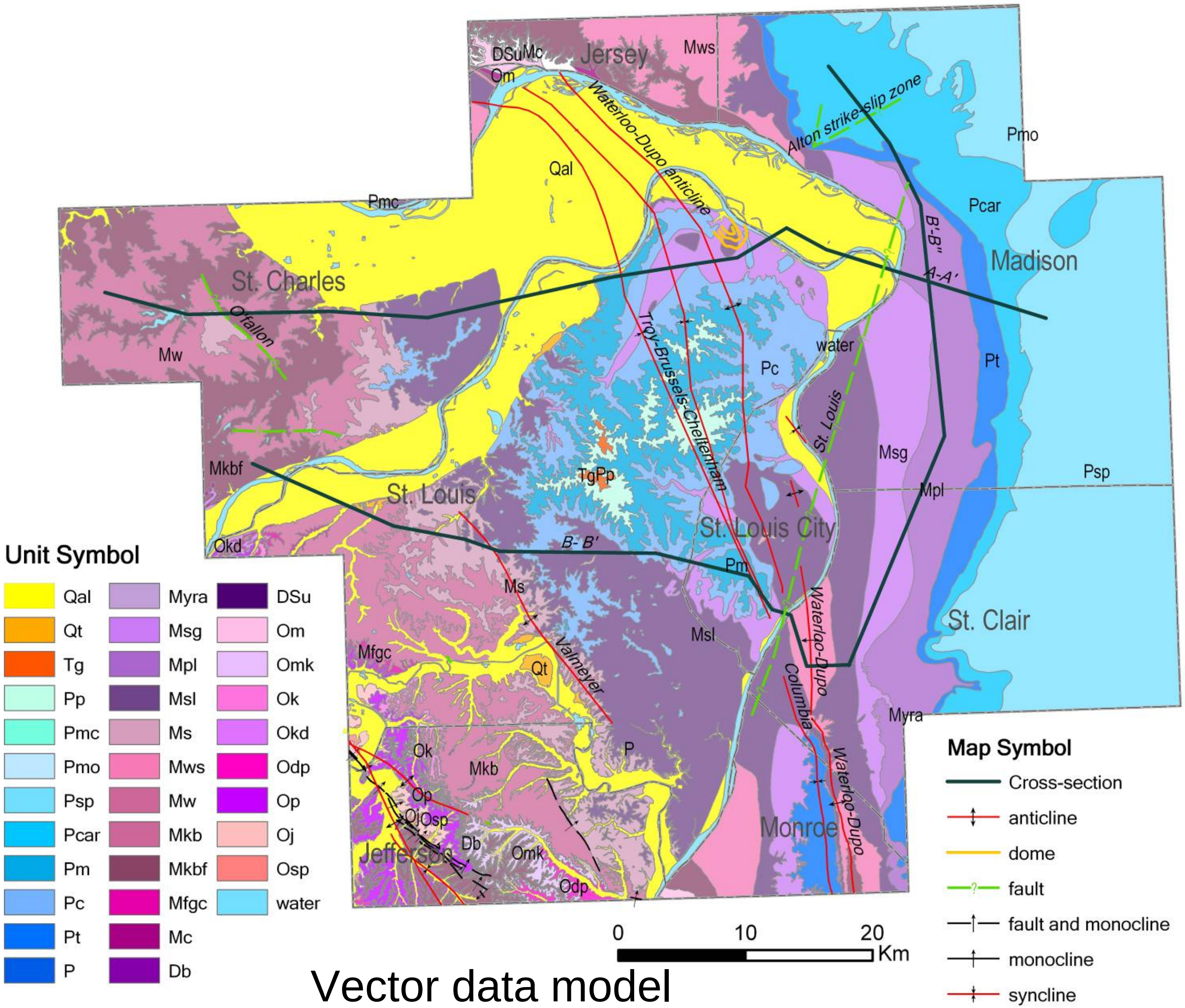
Vector data model

Map Scale Matching Problems

- **Possible Solutions:**
- **For mismatching boundary area, editing another 24K map boundaries instead of 100K map**



Compiled Bedrock Geology Map

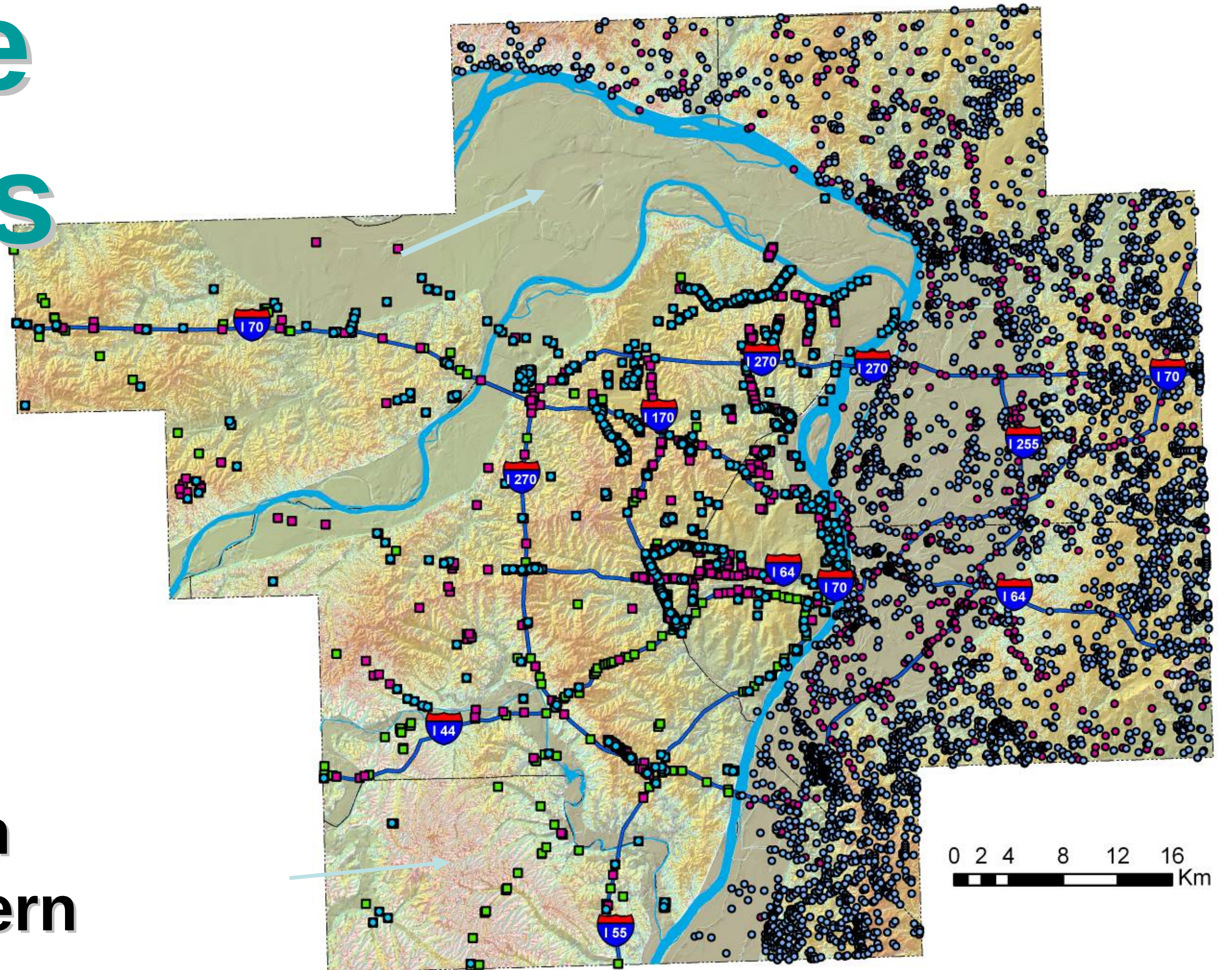


Vector data model

Borehole Locations

- **Data Sources:**
  - **MoDNR-DGLS**
  - **ISGS**

- **Note Data Gaps in Jefferson and eastern St. Charles counties**



Geotechnical boring(MoDGLS)

Borehole Type

- Bedrock depth and type
- Corelog(RQD)
- Grain Size
- Material
- Physical property
- Water observation

Geotechnical boring(ISGS)

Borehole Type

- Highway log
- Highway/Engineering
- Highwayhead
- Log
- Water well

Vector data model

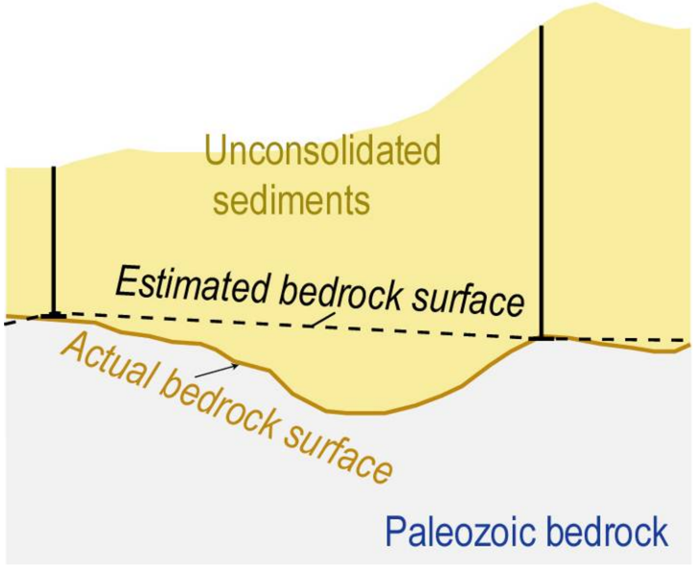
Problems with interpolating the Bedrock Surface

- In undulating terrain, the bedrock surface often presents a complex feature, shaped by numerous erosional and deformational events

- The interpolation in rugged terrain often leads to erroneous results, because:

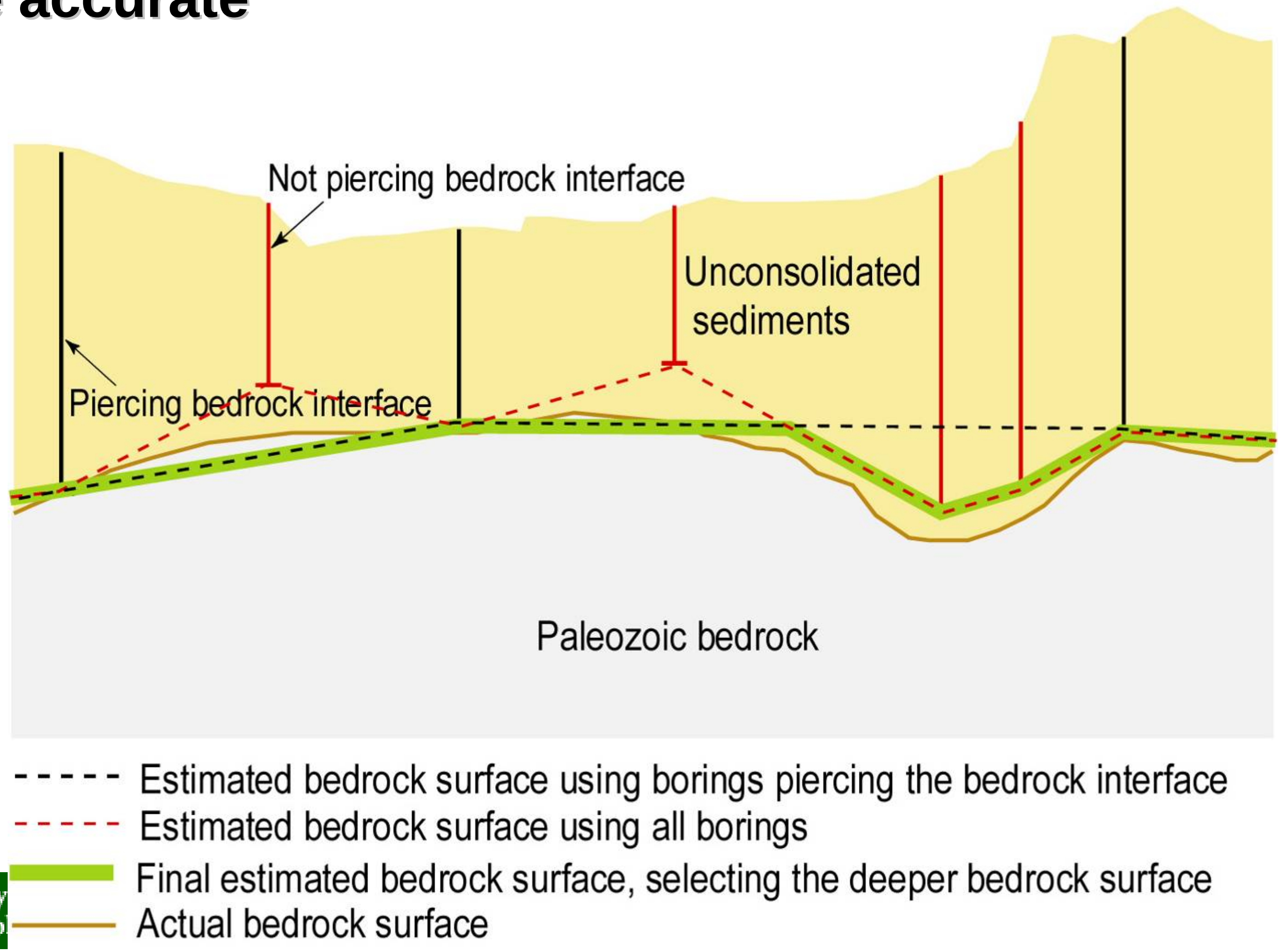
- 1) overestimation of bedrock surfaces in paleovalley systems

- 2) a local contouring model may result in poor estimates when applied to a different geomorphic province or terrain



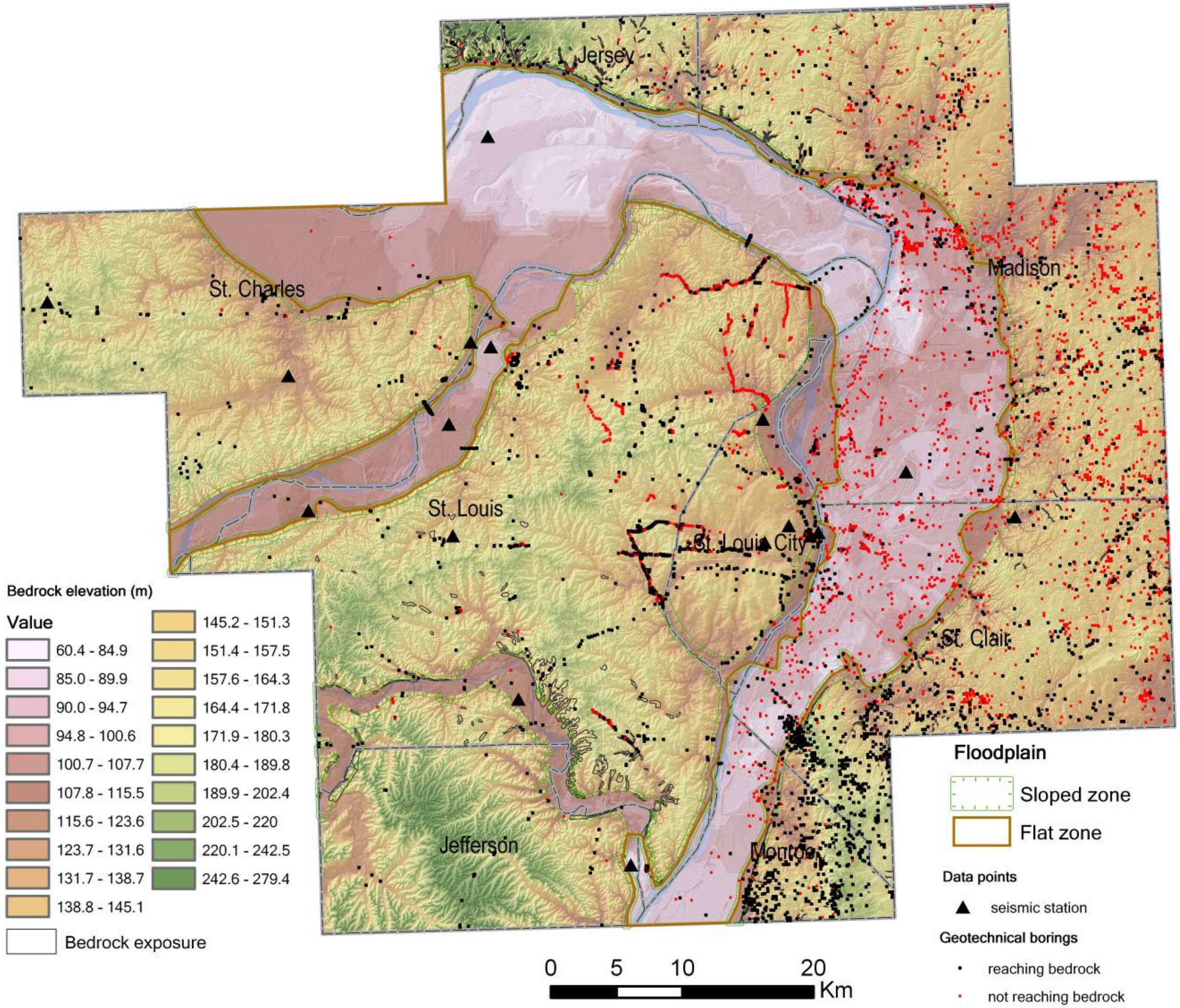
Procedure for Interpolating Depth-to-Bedrock

- **3) Of these two approximations, my model was programmed to select the *deeper bedrock surface*, which appears to be more accurate**



Kriging Map of Bedrock Elevation

subtracted DEM from kriged Depth to Bedrock

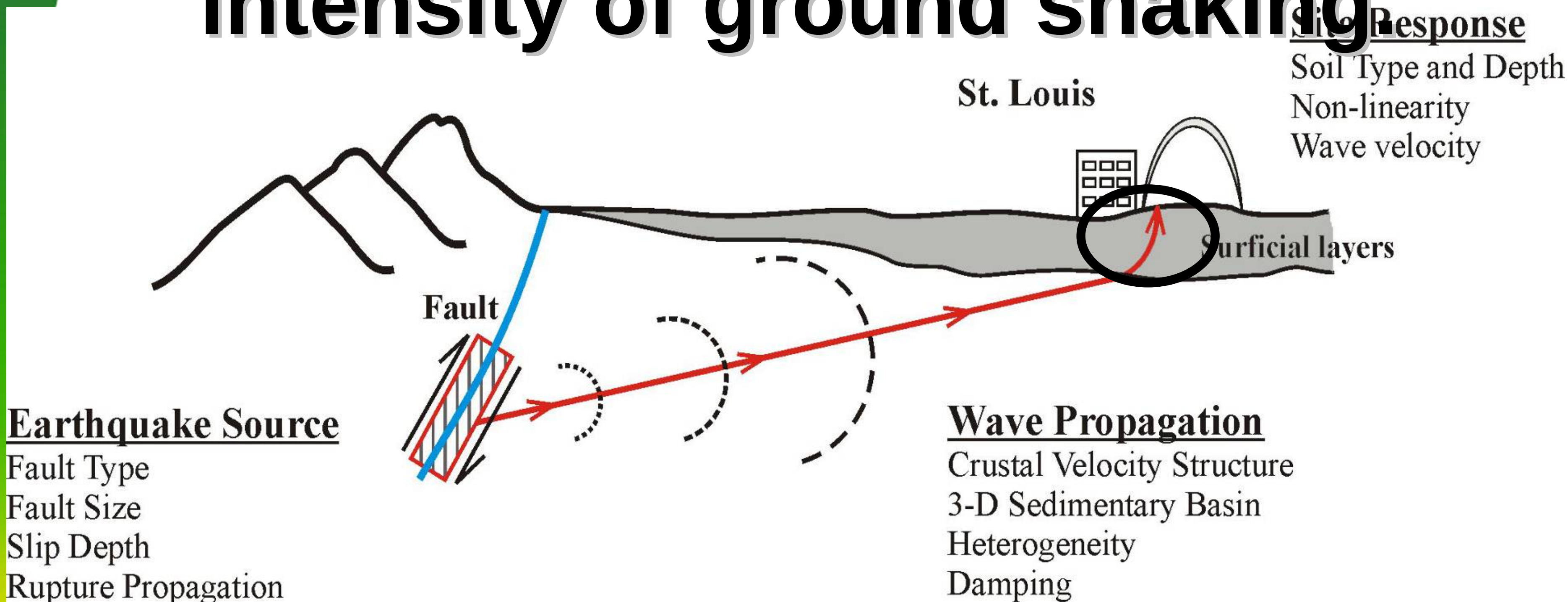


Bedrock elevation (m)

Raster data model

Physical Factors Affecting Seismic Site Response

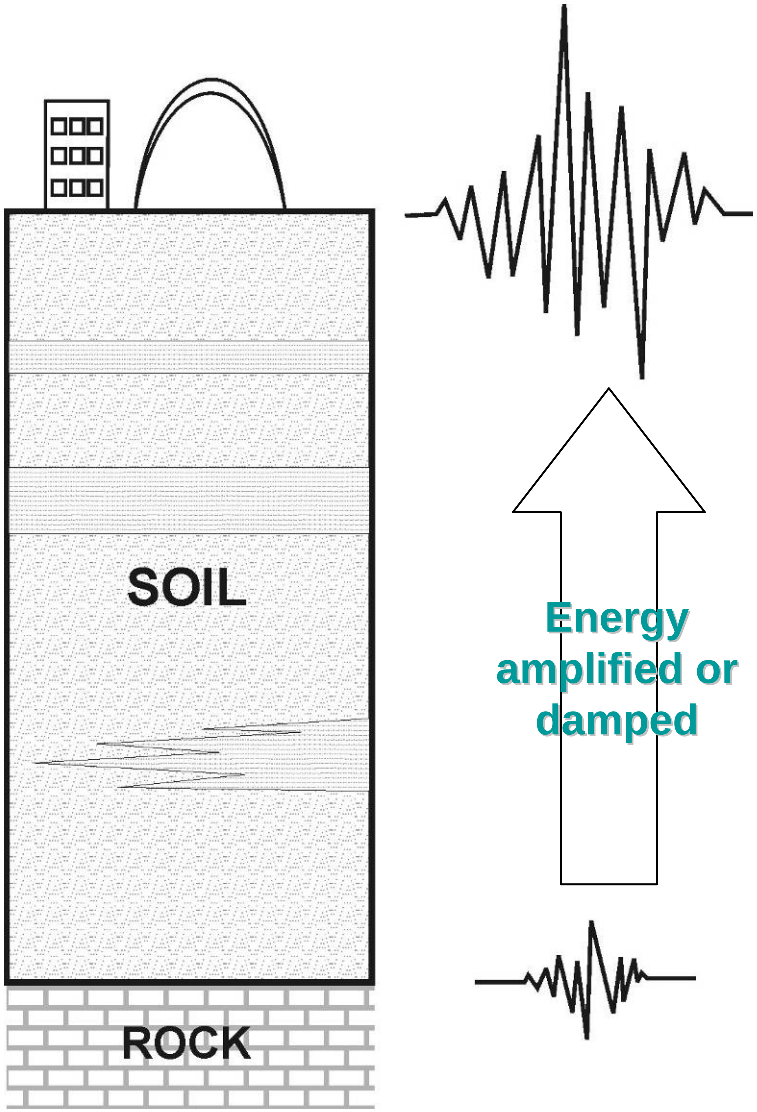
What is Site Response? How the soil under the site affects the intensity of ground shaking.



- The type, depth and size of fault, combined with physical properties of crust and geophysical properties of the surficial soils affect site response.

Estimating surface accelerations

- Surface accelerations can be estimated using 1-D seismic site response software
- Typical input data includes:
  - Soil physical properties
  - Soil dynamic properties
  - Soil thickness
  - Input rock motion at the base of the soil column
- These are combined to estimate the site amplification, or de-amplification

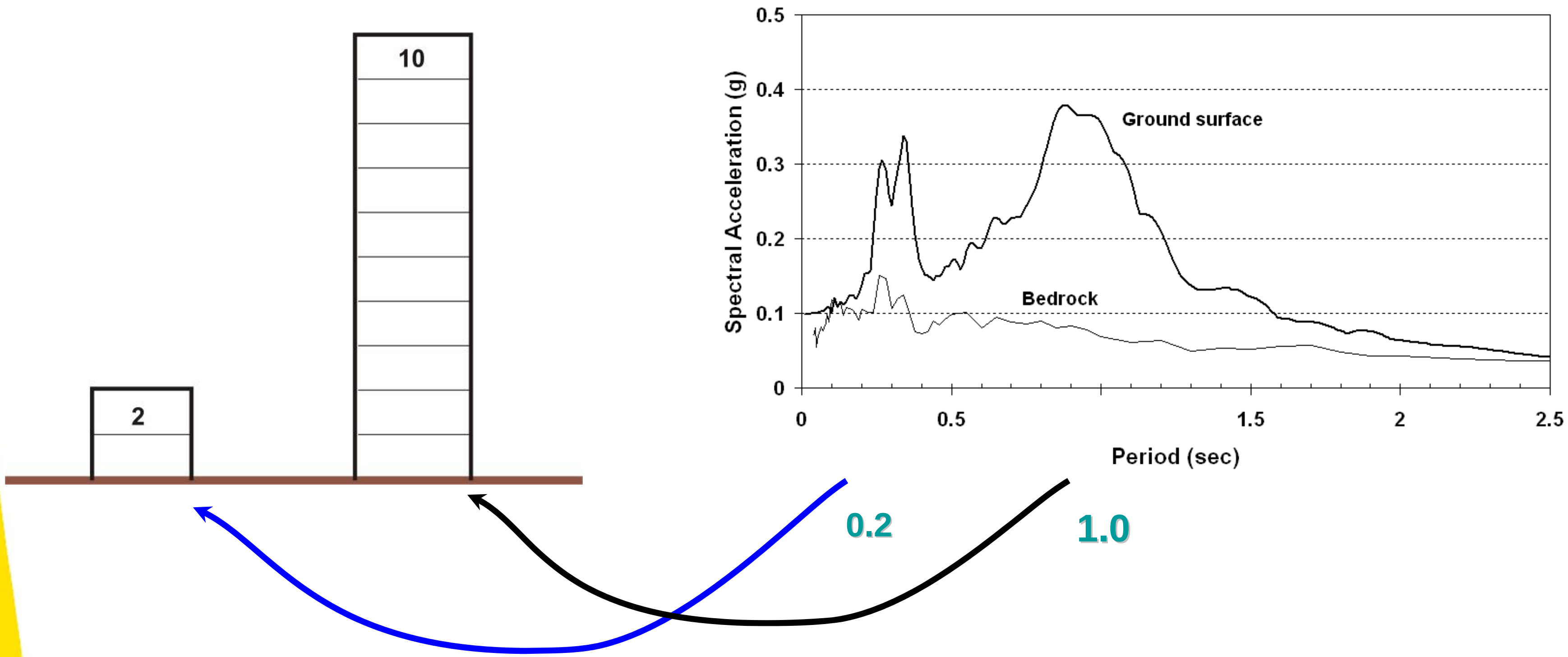


Ground Motion Parameters

- Peak Ground Acceleration (PGA) is the maximum acceleration experienced by the particle during the course of the earthquake motion.
- Spectral Acceleration (SA) what is experienced by a building, as modeled on a massless vertical rod having the same natural period of vibration as the building.

Spectral Accelerations (SA)

- The spectral acceleration value varies with the natural period of the structure.



(approximately related)

The MS&T pilot study sought to develop the following maps, of a ~460 km^2 land area.

- 1) Site amplification maps for different levels of ground shaking (0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0) in terms of PGA, 0.2 sec and 1 sec spectral accelerations.
- 2) 2% probability of exceedance in 50 years in terms of PGA;
- 3) 5% probability of exceedance in 50 years in terms of PGA;
- 4) 10% probability of exceedance in 50 years in terms of PGA;
- 5) 0.2 second spectral accelerations for 2%, 5% and 10% probabilities of exceedance in 50 years;
- 6) 1 second spectral accelerations for 2%, 5% and 10% probabilities of exceedance in 50 years;
- 7) 2 scenario earthquakes (M_o 7.0 and 7.7) and their associated PGA and 0.2 sec-SA and 1 sec-SA;

Distribution of Site Amplification and Development of Site Amplification Maps

What information do we need to estimate site amplification?

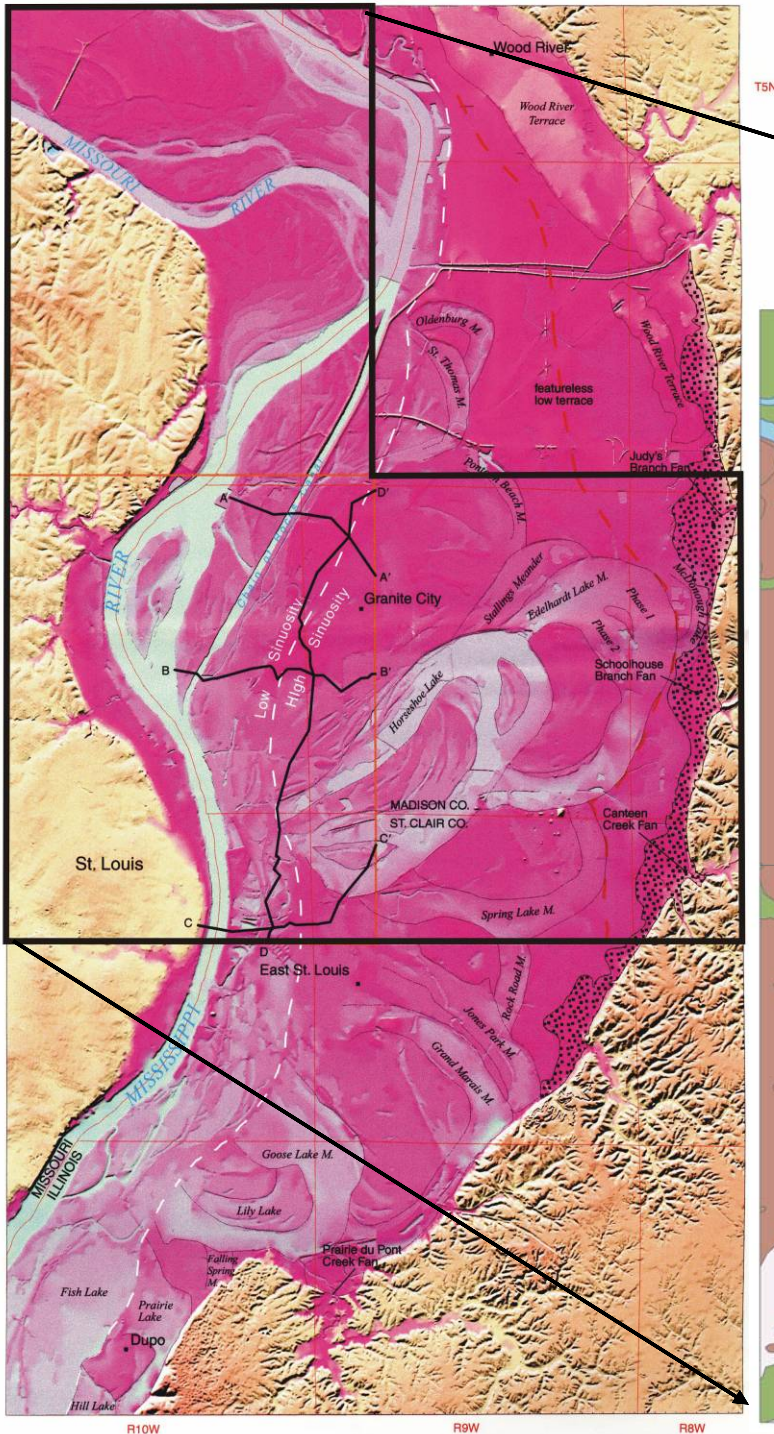
- 1) **Characterize the shallow geology overlying the bedrock**
- **Surficial geology maps**
- **Depth to Bedrock**

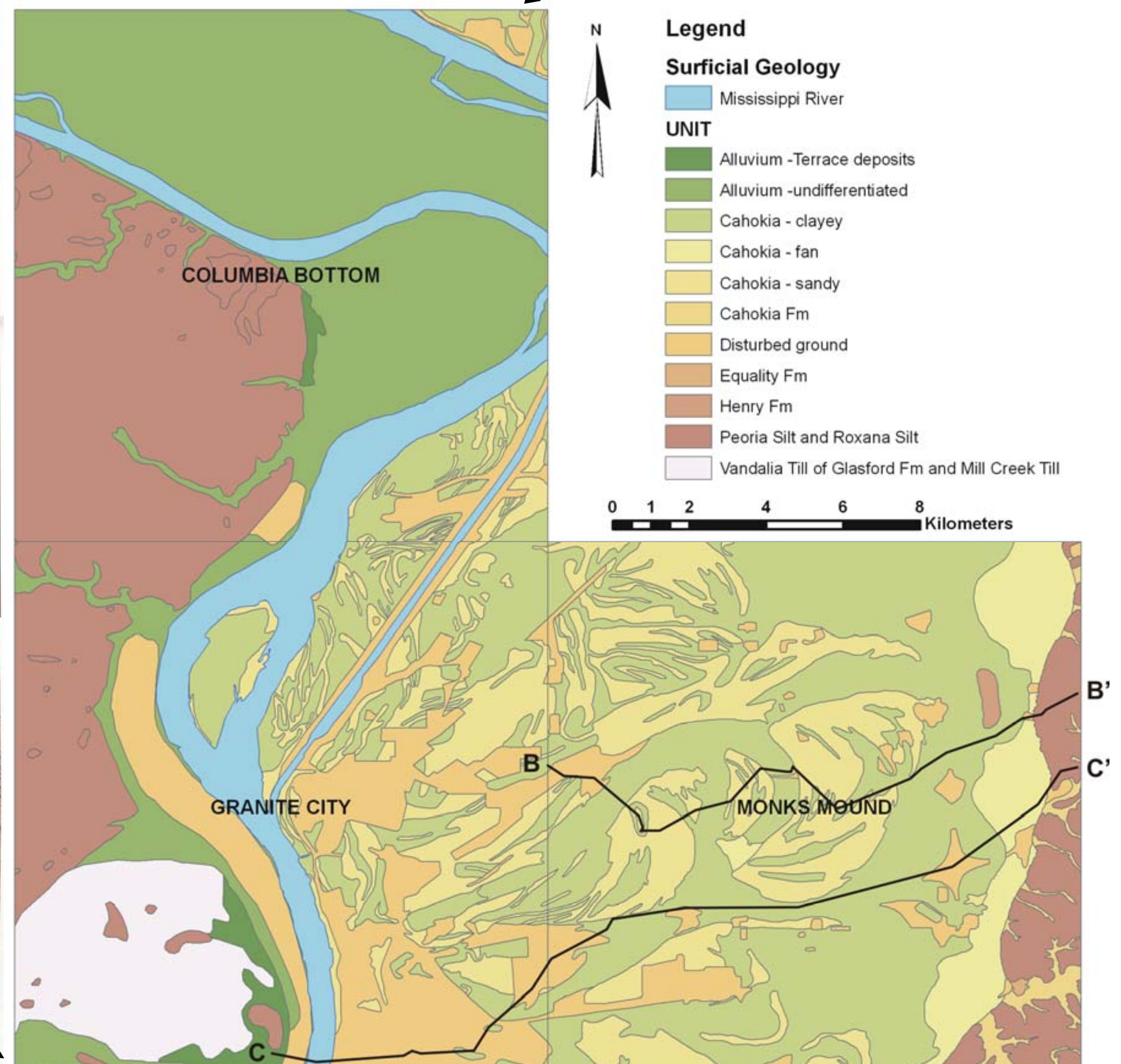
- **2) Characterize the bedrock acceleration**

- **3) Characterize the thickness and shear wave velocity of the bedrock underlying the surficial materials**

- **4) Characterize the properties of the surficial materials (~soil cap)**
- **Physical soil properties**
- **Dynamic soil properties (shear modulus and damping, shear wave velocity)**

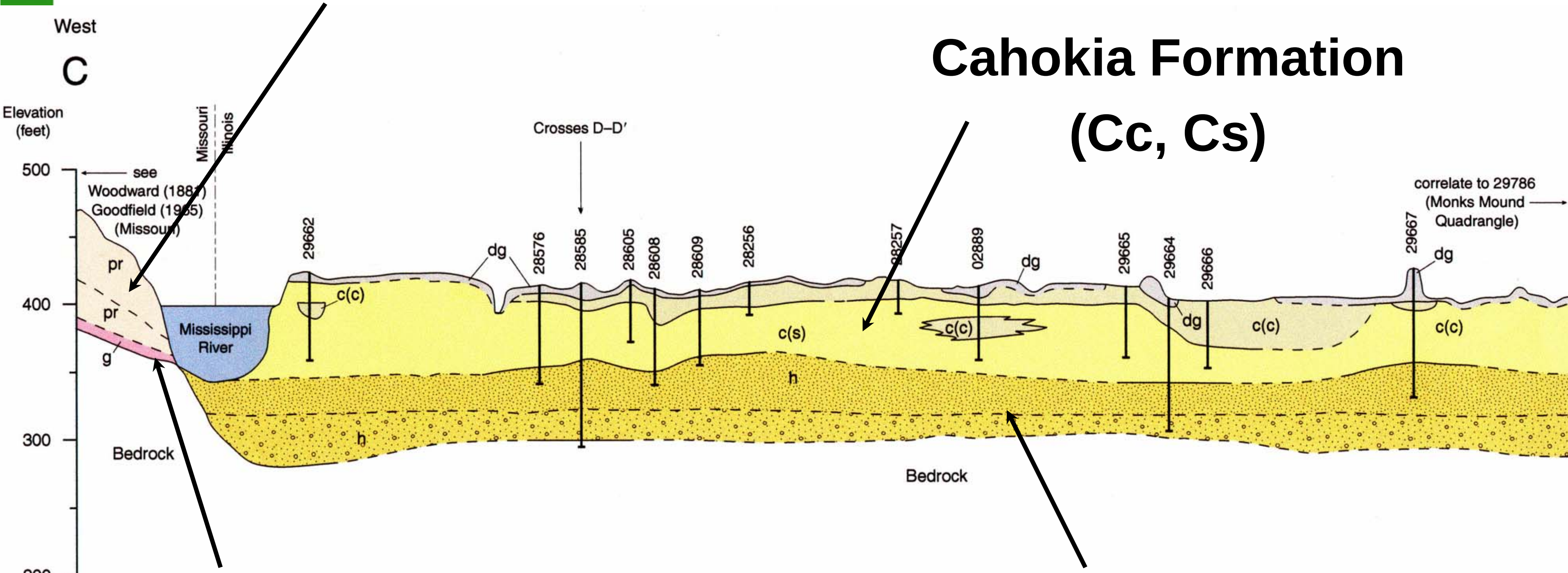
Surficial Geology of St. Louis study area





Typical Cross section thru Mississippi flood plain

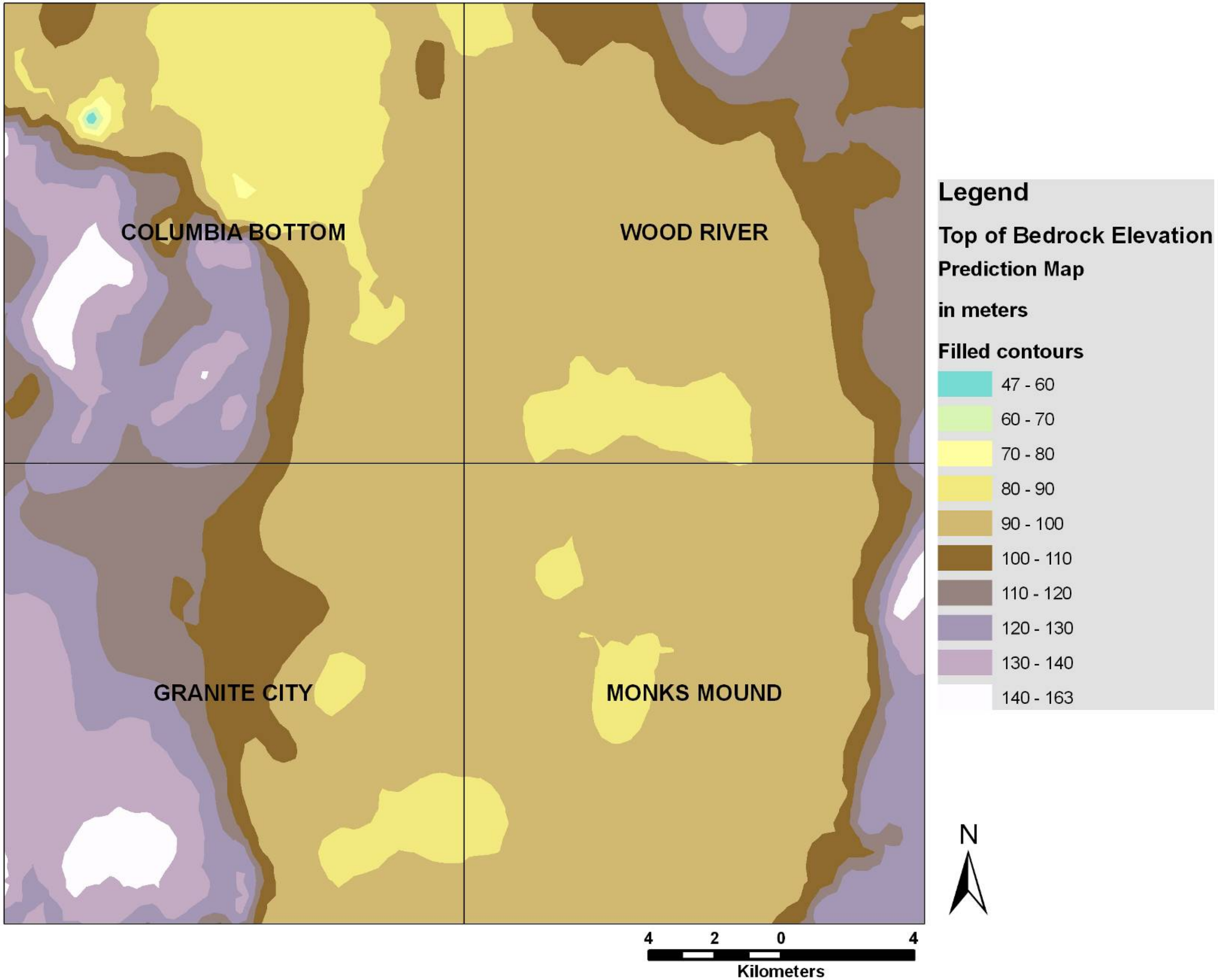
Peoria and Roxana Silt -loess

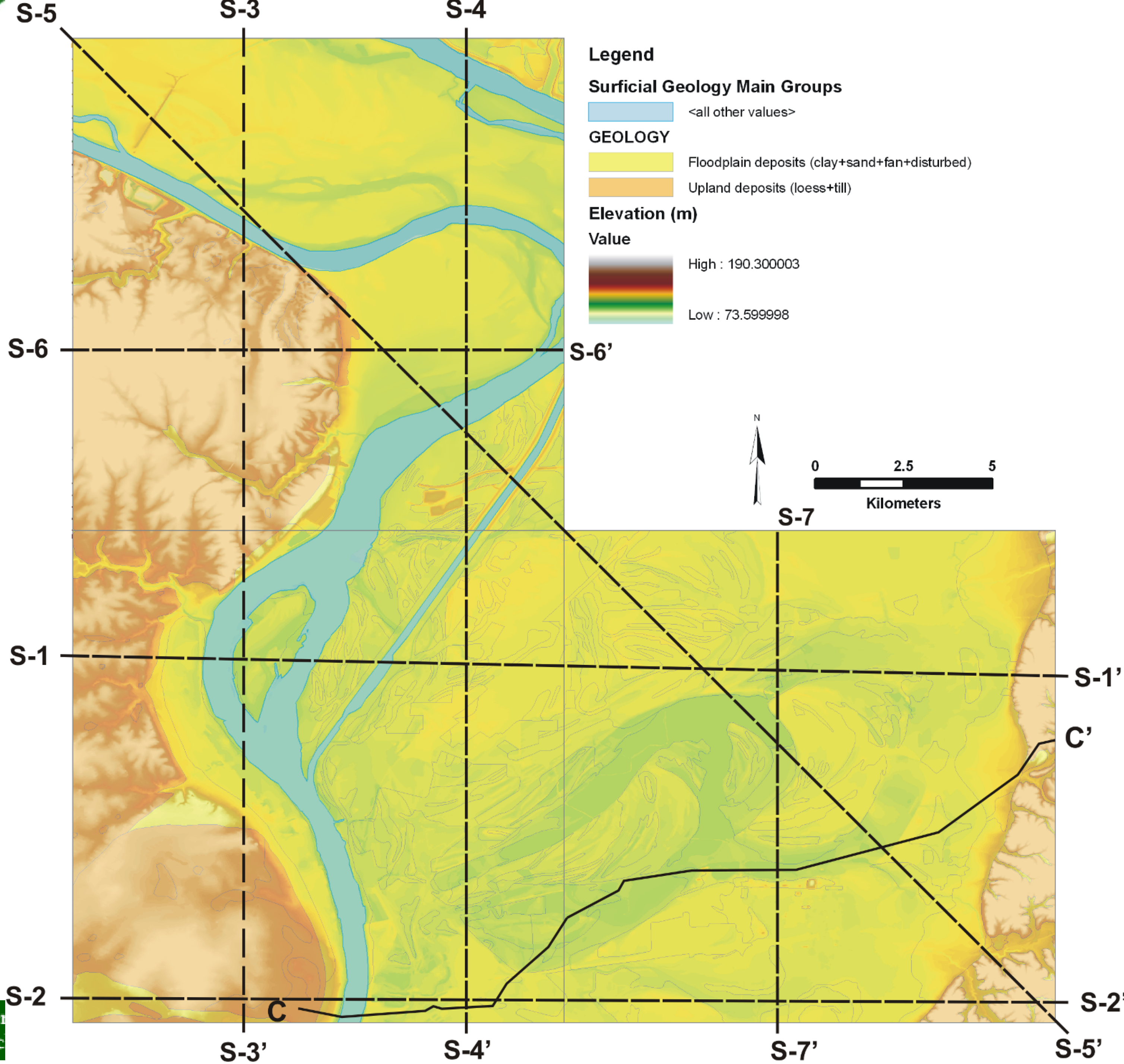


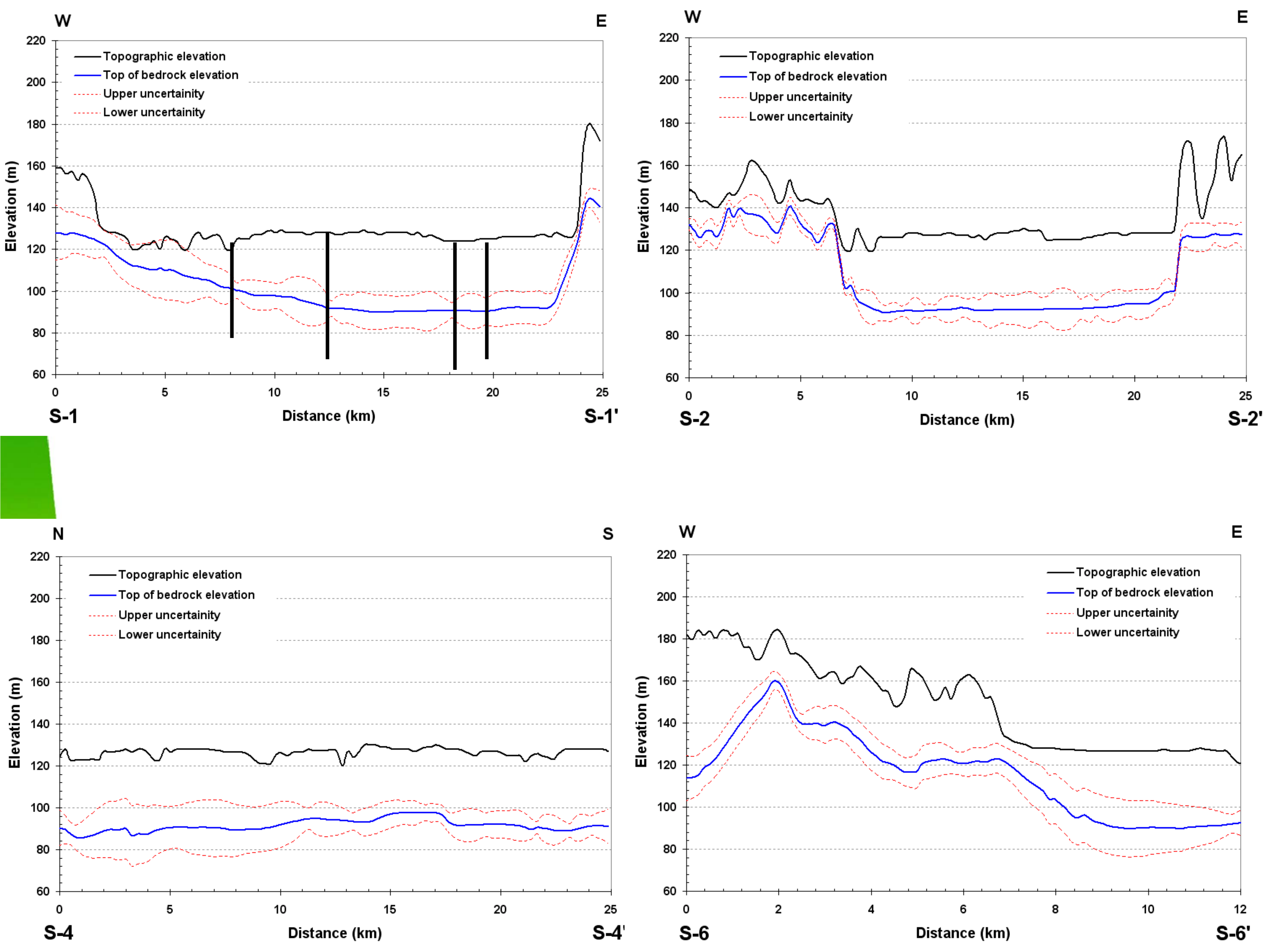
Glasford formation -till

Henry Formation (h)

Estimation of Top of Bedrock Elevations

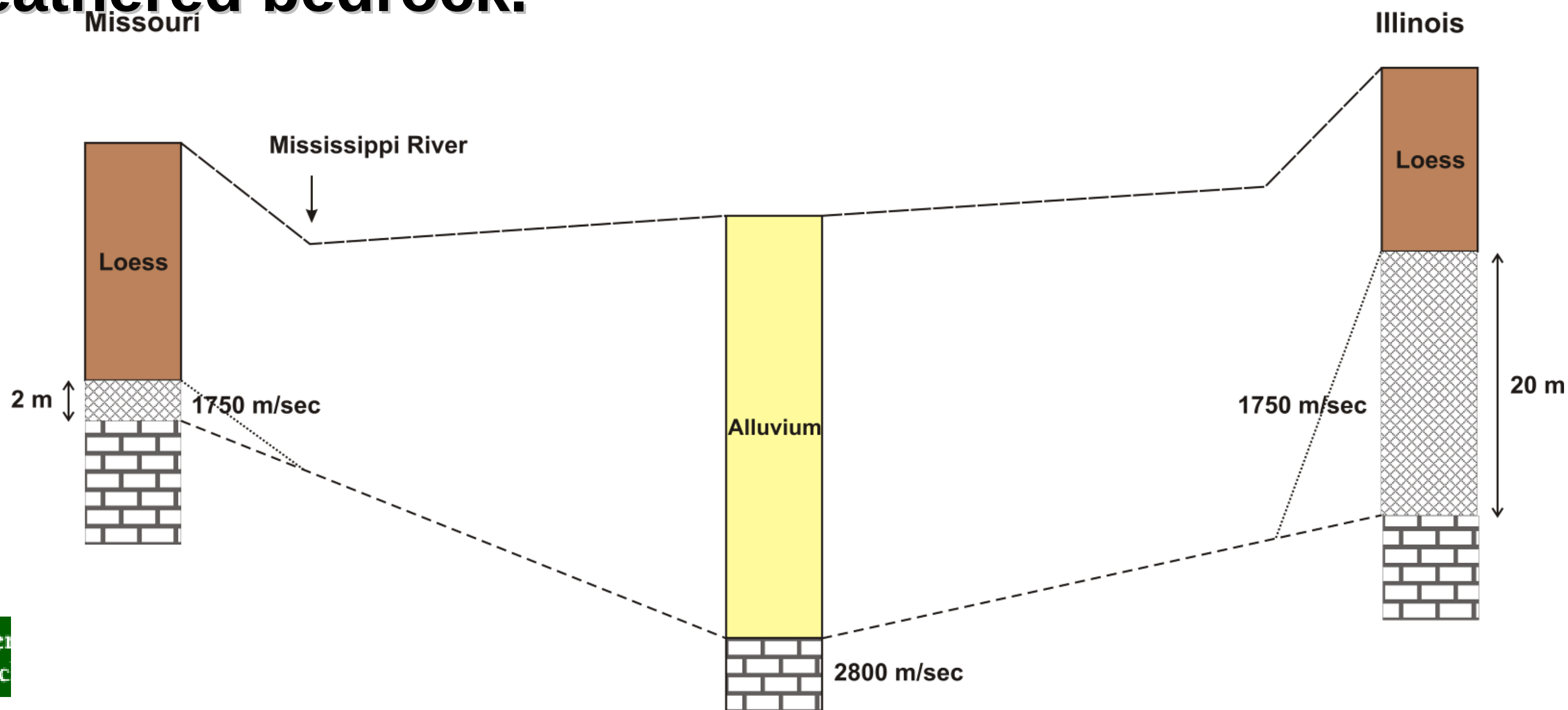



Legend
Surficial Geology Main Groups
<all other values>
GEOLOGY
Floodplain deposits (clay+sand+fan+disturbed)
Upland deposits (loess+till)
Elevation (m)
Value
High : 190.300003
Low : 73.599998
N
0
2.5
5
Kilometers
S-5
S-3
S-4
S-6
S-6'
S-7
S-1
S-1'
C'
S-2
S-2'
C
S-3'
S-4'
S-7'
S-5'

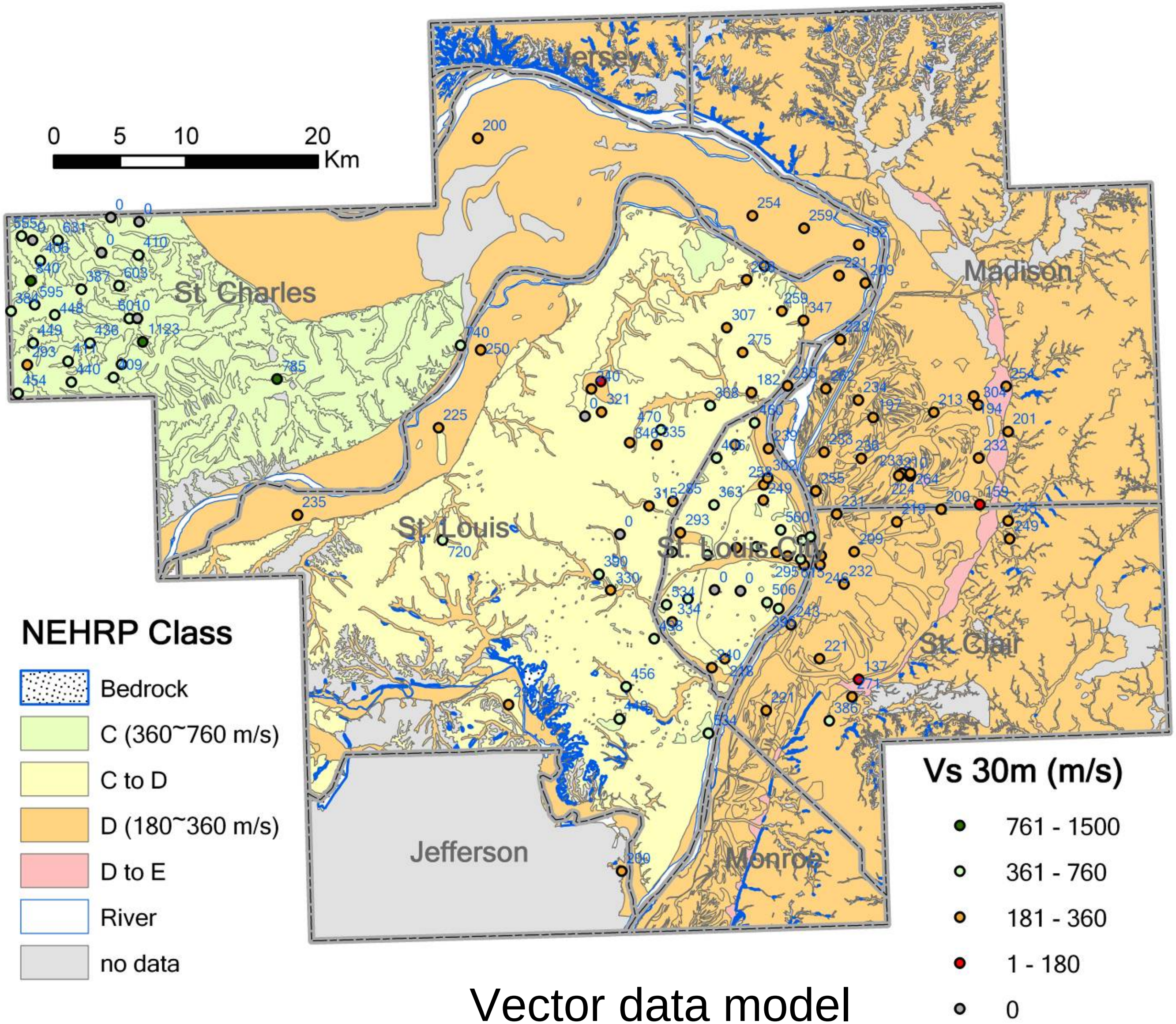

W
E
Topographic elevation
Top of bedrock elevation
Upper uncertainity
Lower uncertainity
Elevation (m)
Distance (km)
S-1
S-1'
W
E
Topographic elevation
Top of bedrock elevation
Upper uncertainity
Lower uncertainity
Elevation (m)
Distance (km)
S-2
S-2'
N
S
Topographic elevation
Top of bedrock elevation
Upper uncertainity
Lower uncertainity
Elevation (m)
Distance (km)
S-4
S-4'
W
E
Topographic elevation
Top of bedrock elevation
Upper uncertainity
Lower uncertainity
Elevation (m)
Distance (km)
S-6
S-6'

Bedrock properties

- We used 1750 m/sec +/- 250 m/sec for the weathered bedrock shear-wave velocity, as suggested by Prof. Robert Herrmann at St. Louis University.
- We selected 0m / 2m / 20 m thicknesses for the weathered bedrock.
- We also used 2800 m/sec for the half-space below the weathered bedrock.



Preliminary NEHRP Soil Classification Map (mean Vs_{30m} / Surficial Geology)



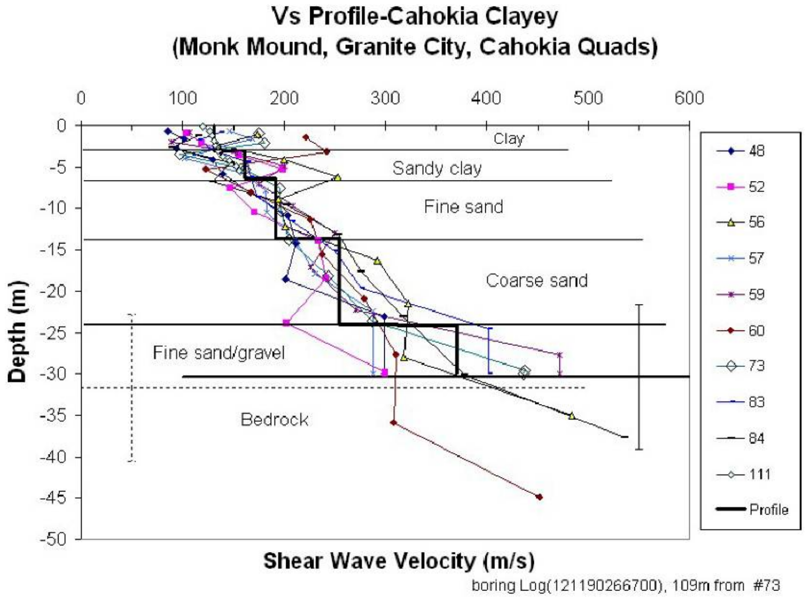
Vector data model

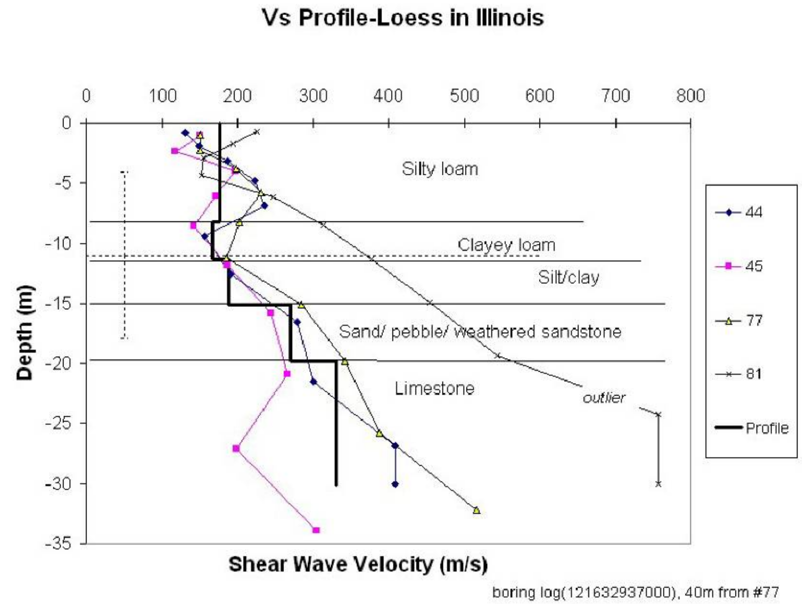
Vs_{30m} and NEHRP Soil Classes

- Vs_{30m} = average Vs in the upper 30m
- The higher Vs_{30m}, the stiffer materials

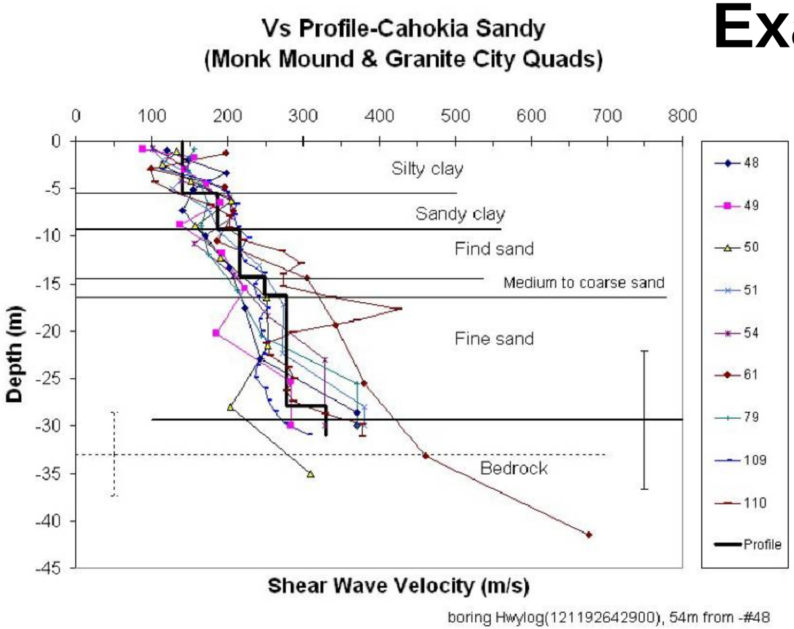
Site Class	Avg. Vs (m/s) in the upper 30m	General Description
A	Vs >1500	Hard rock
B	760<Vs<=1500	Rock with moderate fracturing and weathering
C	360<Vs<= 760	Very dense soil, soft rock, highly fractured and weathered rock
D	180<Vs<=360	Stiff soil
E	Vs <=180	Soft clay soil
F		Soils requring site-specific evaluations

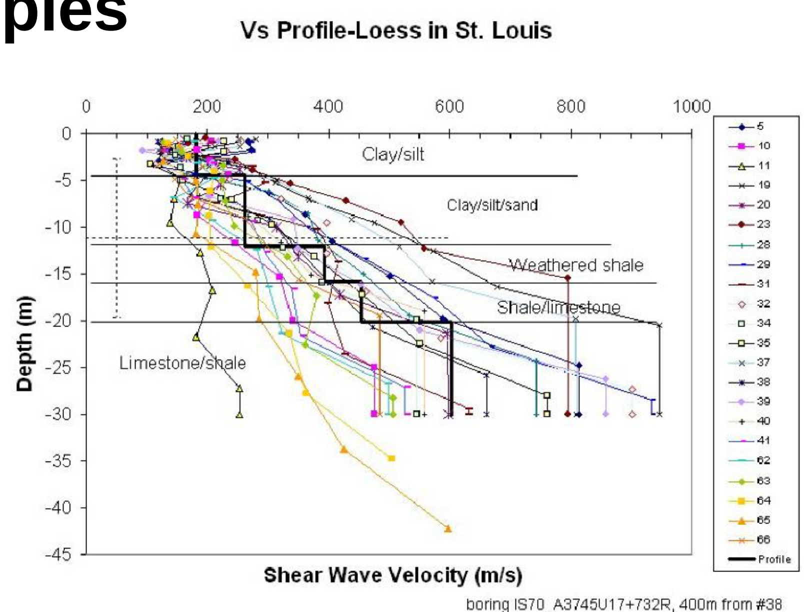
Vs Reference Profiles and Soil Columns derived from adjacent boreholes



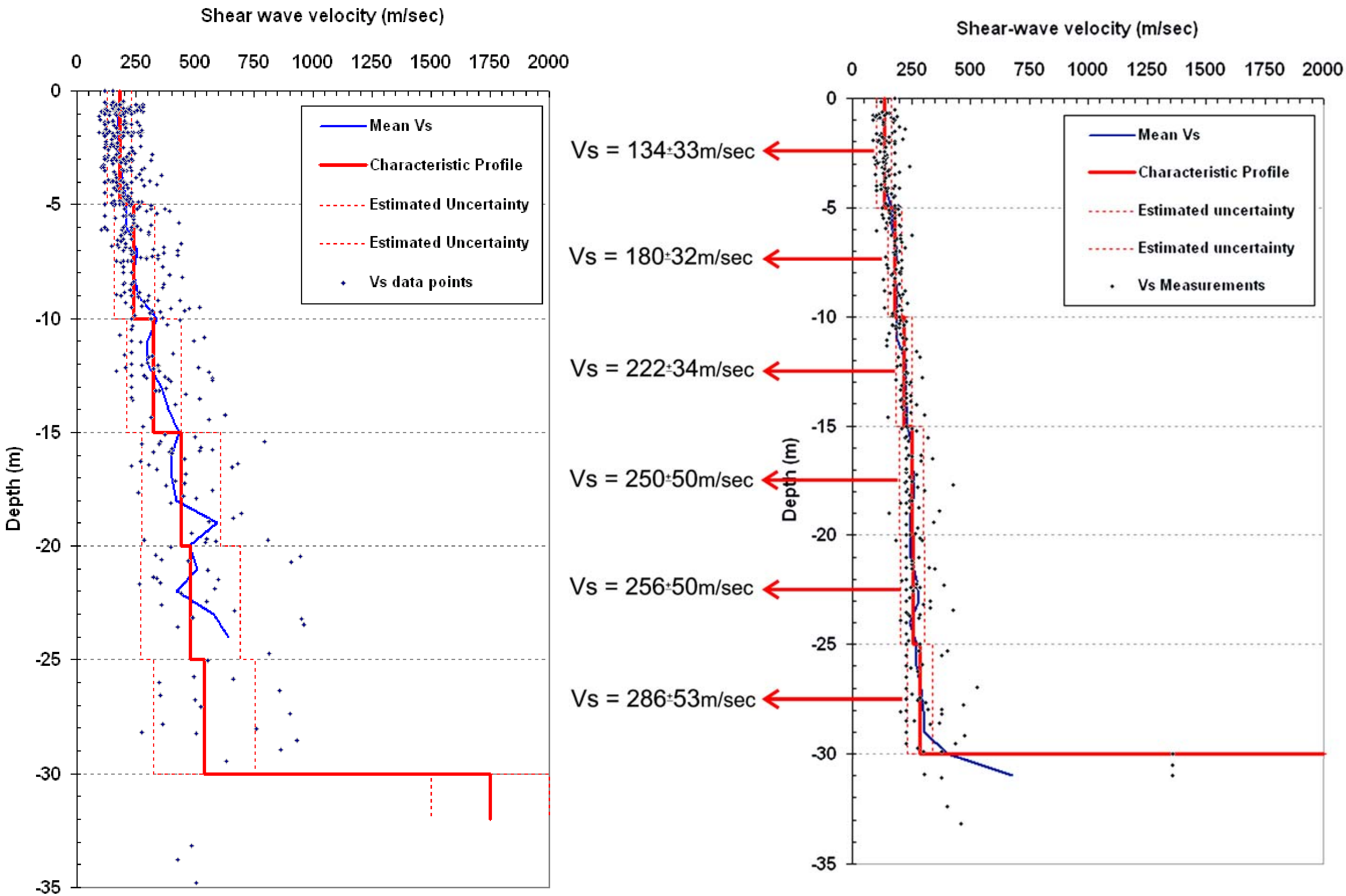


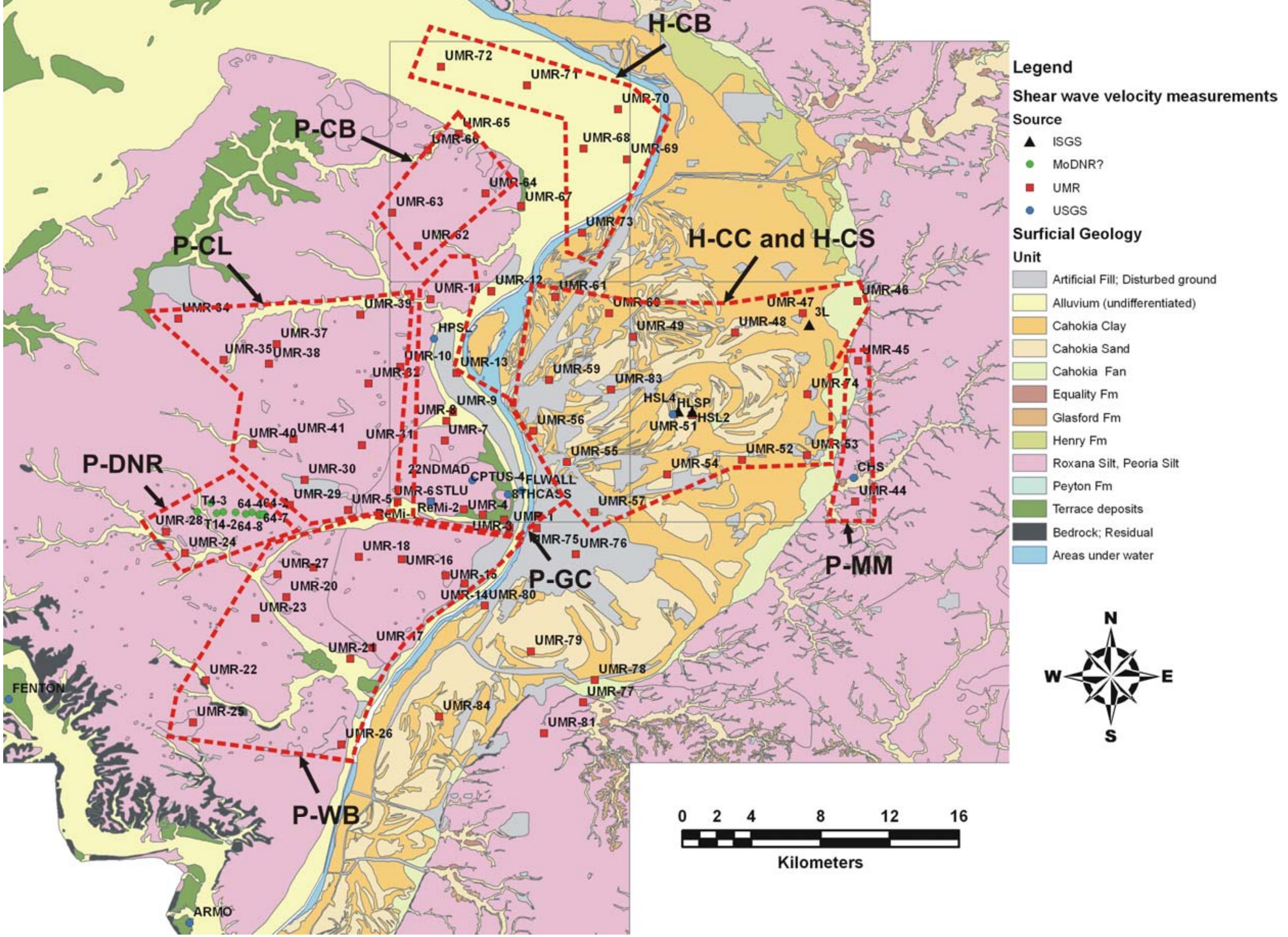
Examples



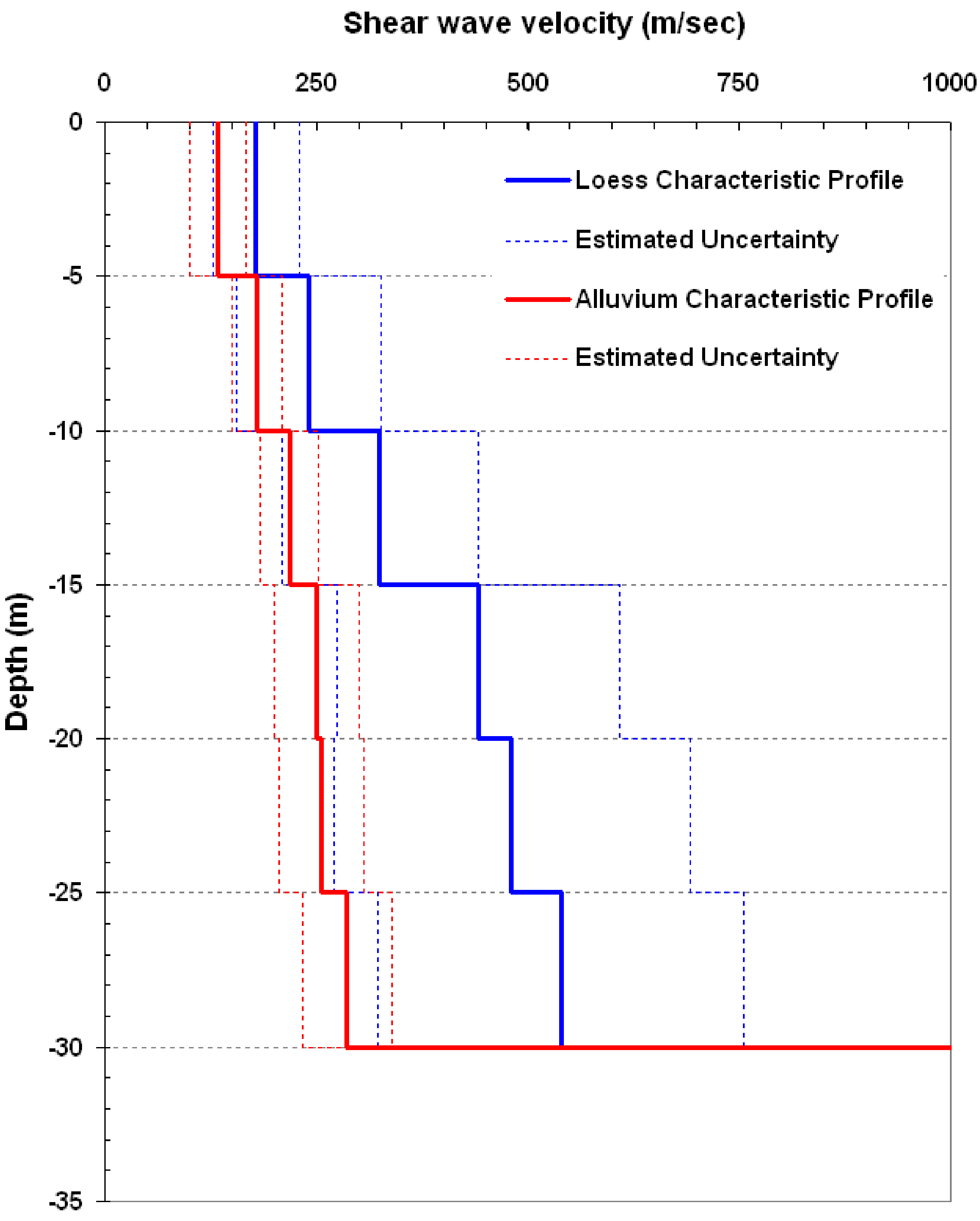


V_s Reference Profiles





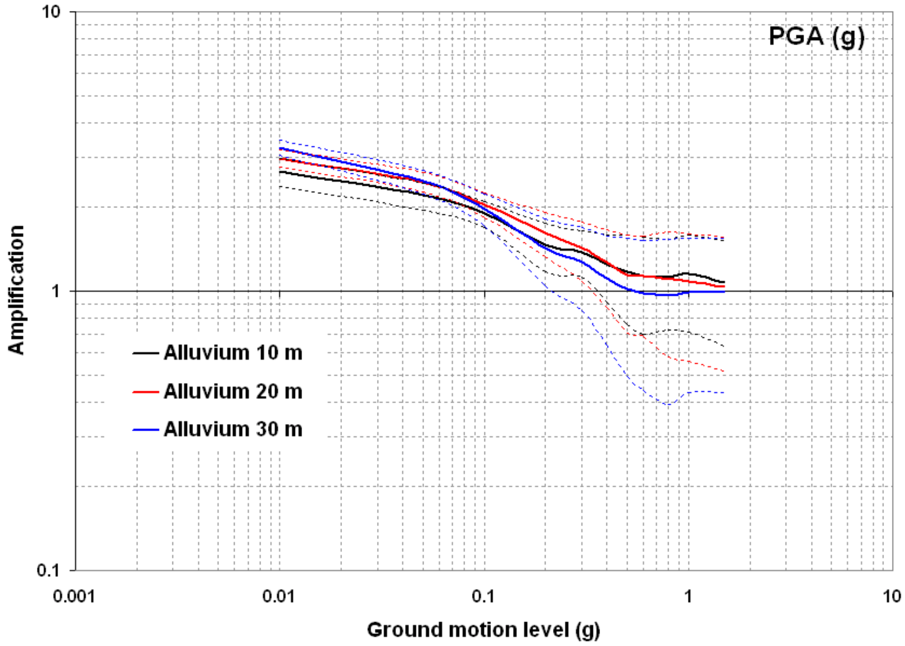
- **Characteristic Vs profiles were developed for 9 geological terrains, such as alluvial or loess/colluvial covered uplands.**

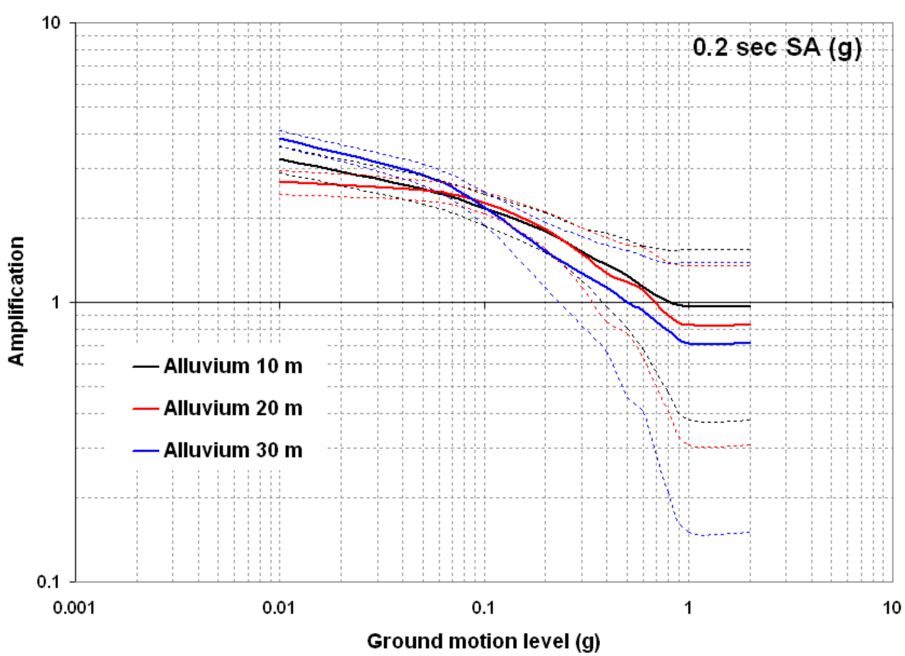


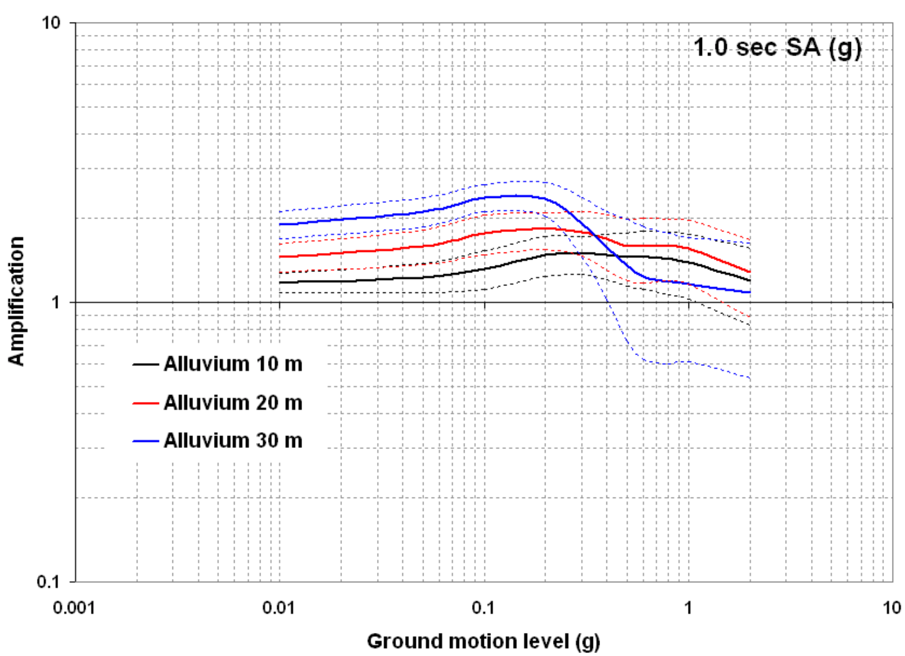
Alluvium vs. Loess

Distribution of Site Amplification

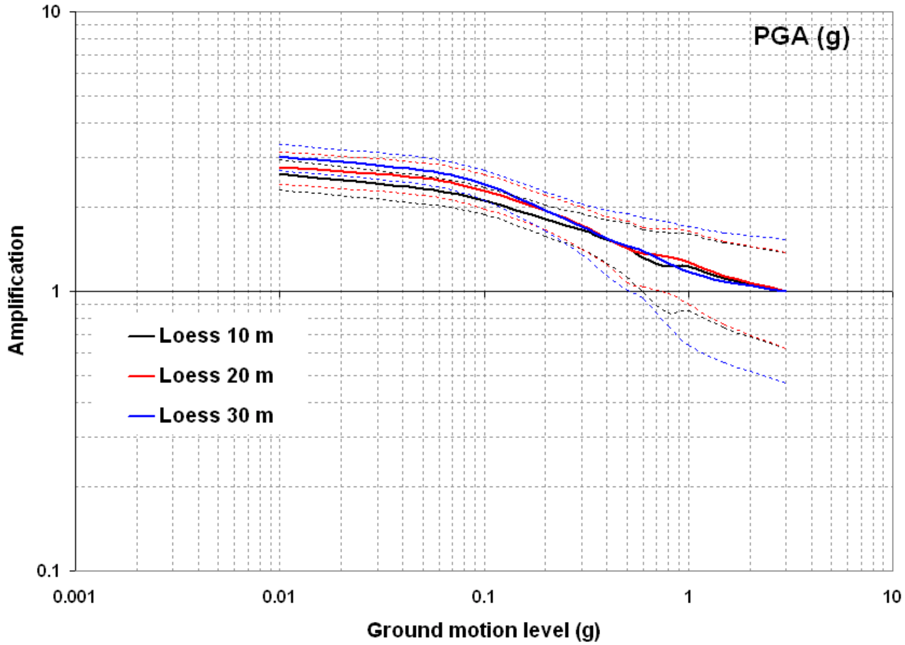
Distribution of Site Amplification in Alluvium

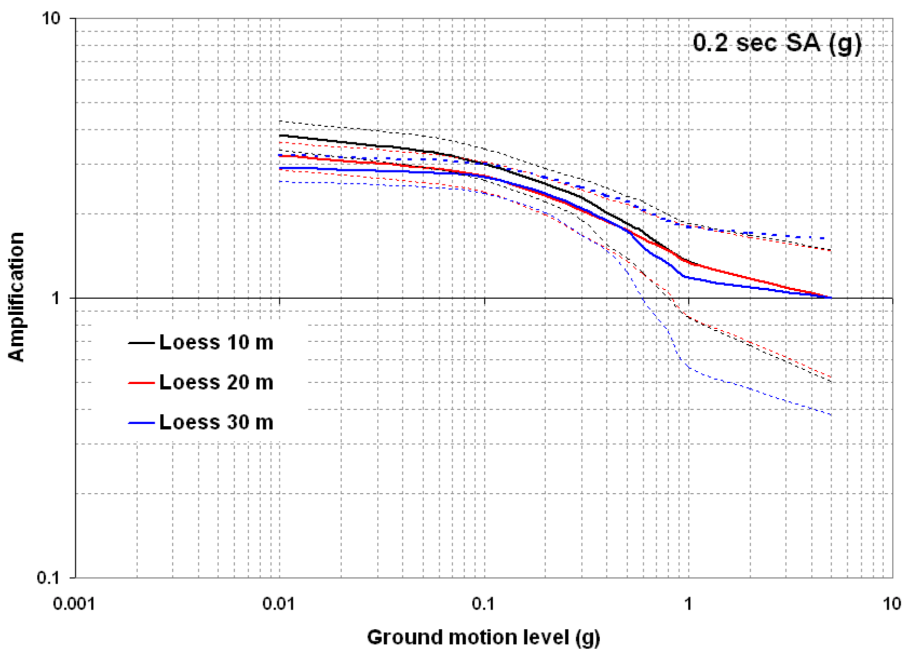


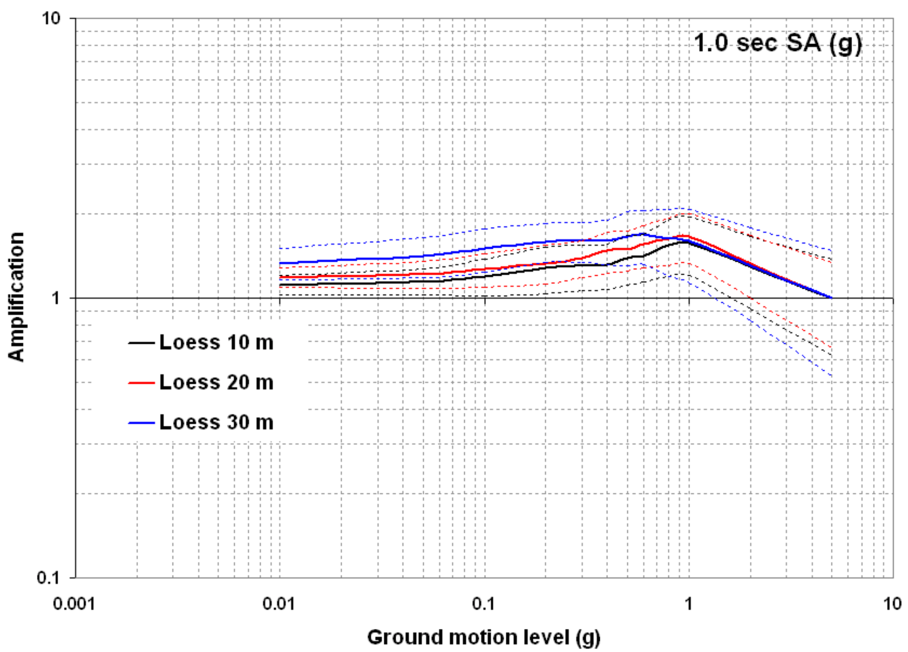




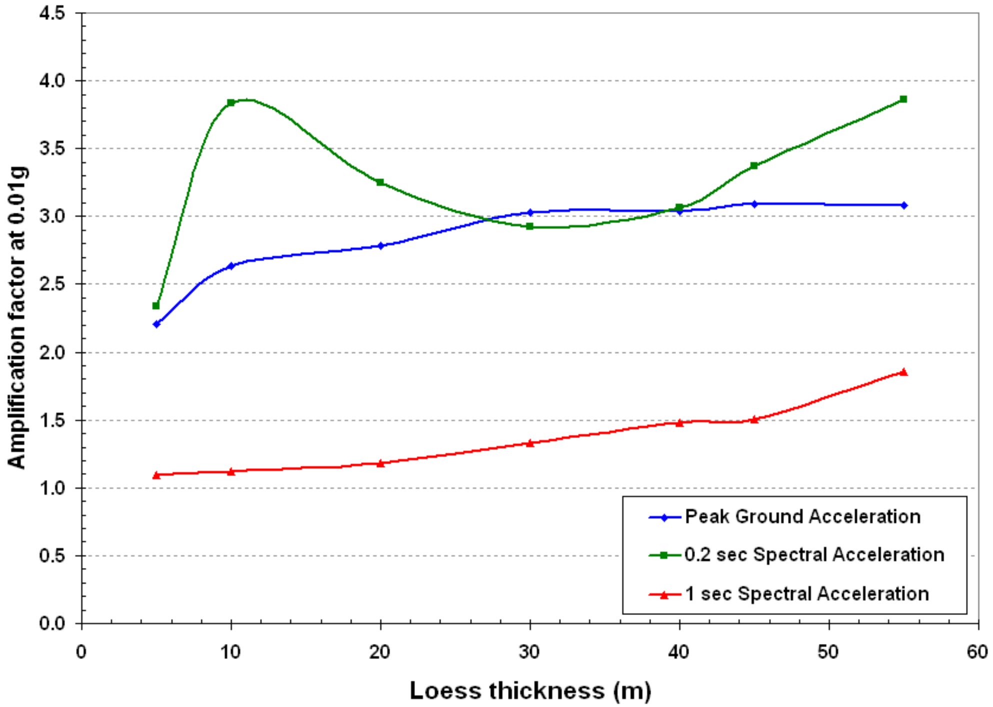
Distribution of Site Amplification in Loess





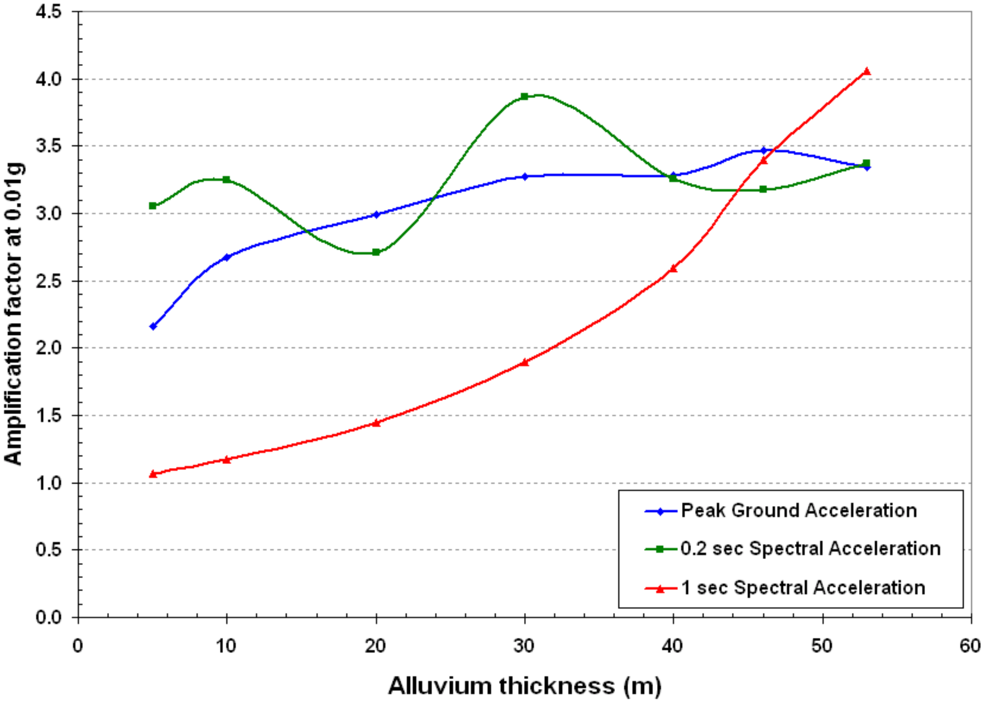


Thickness of soil cap vs. Ground motion



Upland Profiles

Floodplain Profiles



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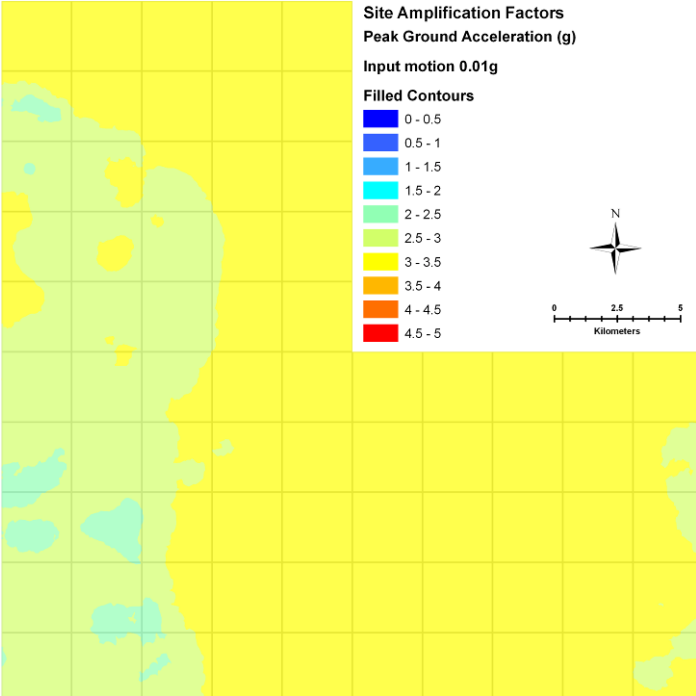
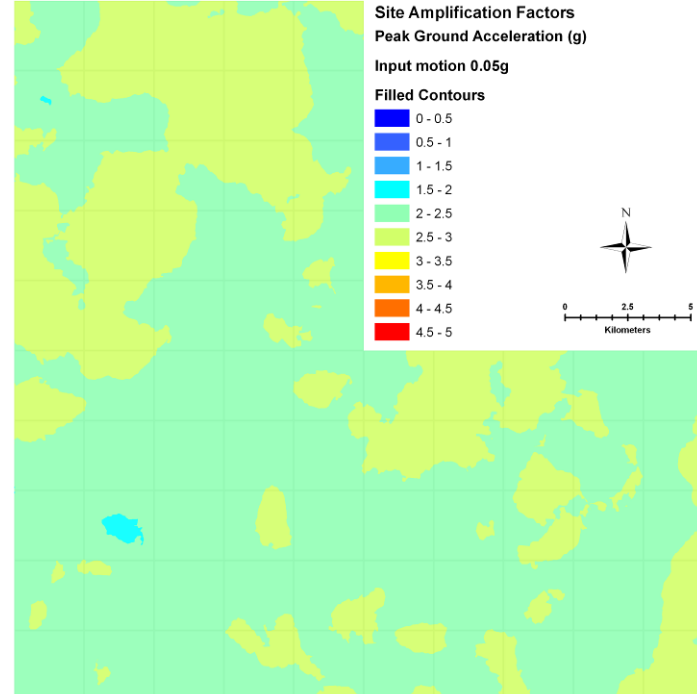
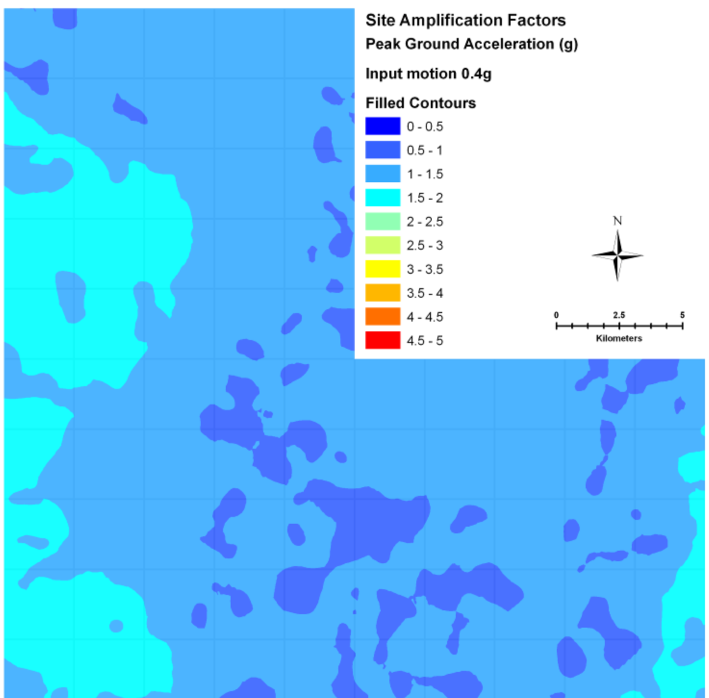
Site Amplification Maps

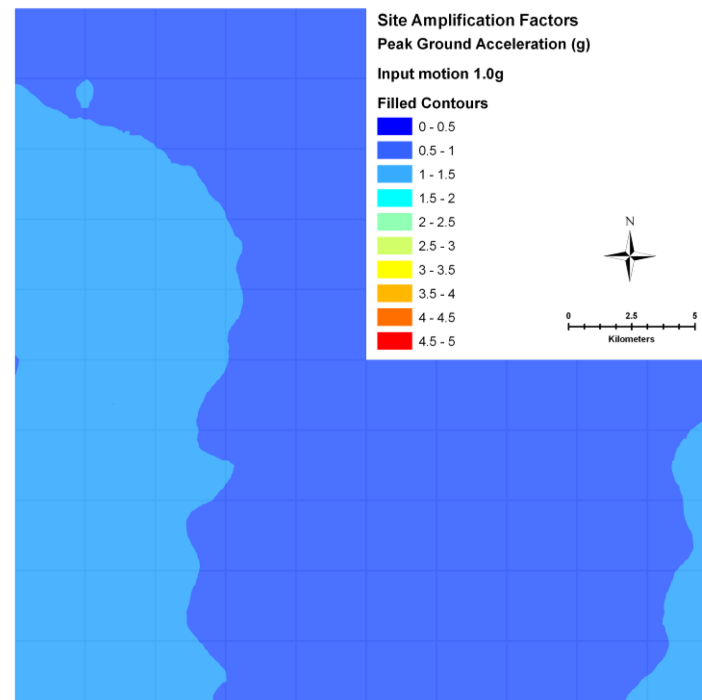
- Site amplification maps are generated for every ground motion level of earthquake input and for ground motion parameters :
  - Peak Ground Acceleration (PGA)
  - 0.2 sec Spectral Acceleration
  - 1.0 sec Spectral Acceleration

PGA (g)

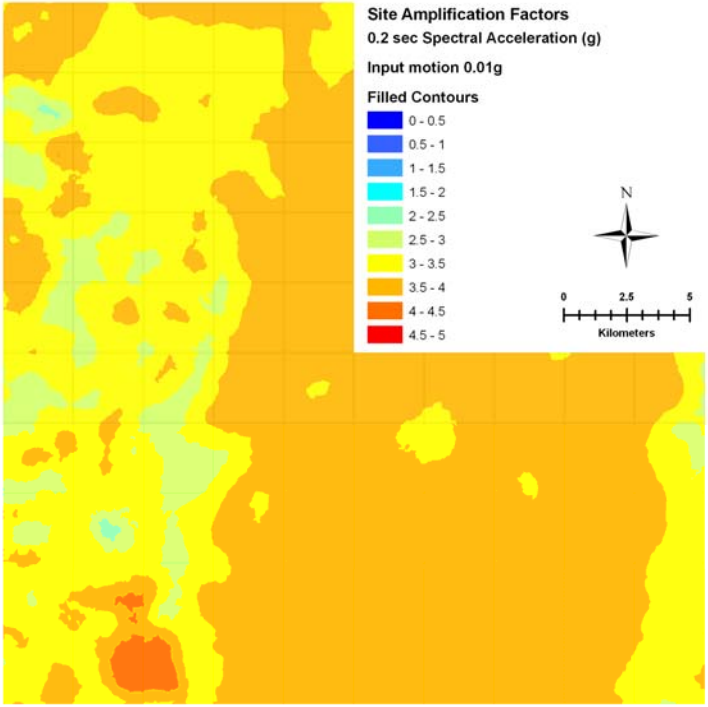

Site Amplification Factors
Peak Ground Acceleration (g)
Input motion 0.01g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

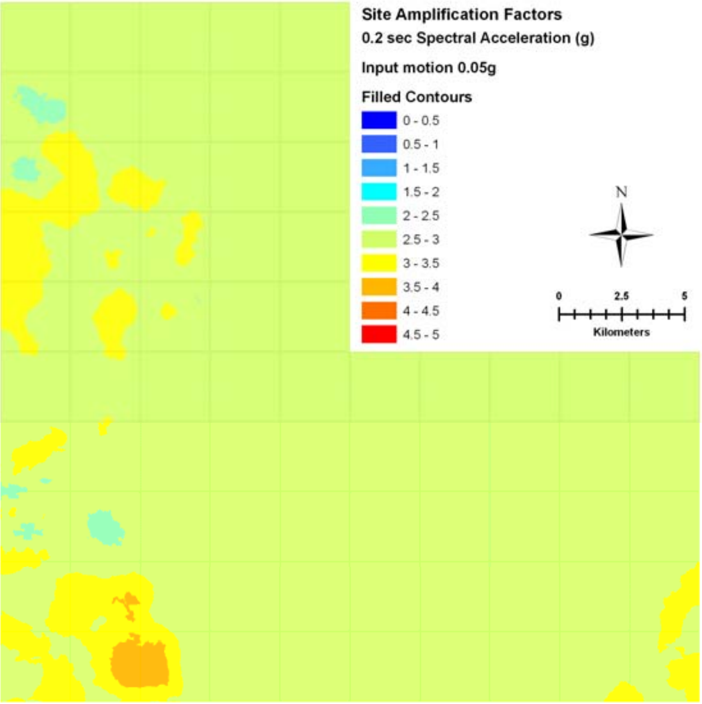

Site Amplification Factors
Peak Ground Acceleration (g)
Input motion 0.05g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

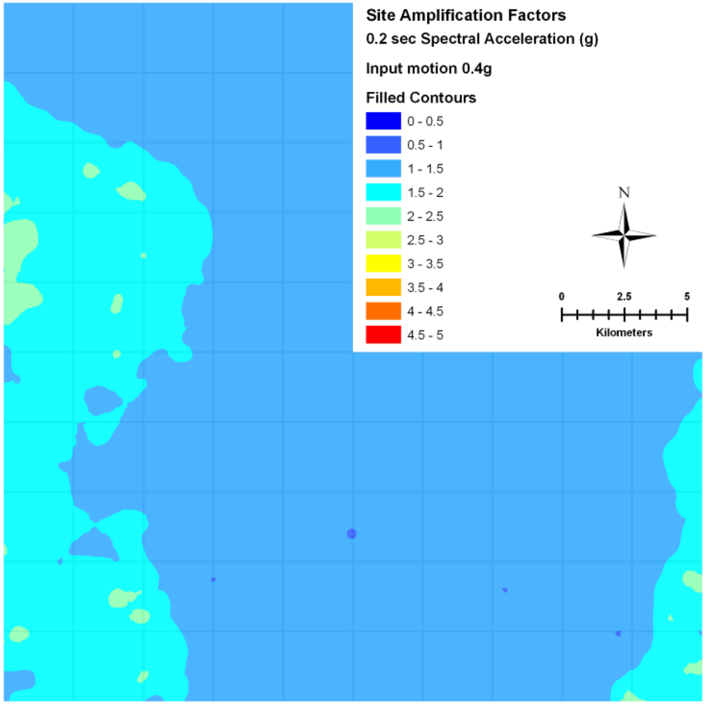

Site Amplification Factors
Peak Ground Acceleration (g)
Input motion 0.4g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

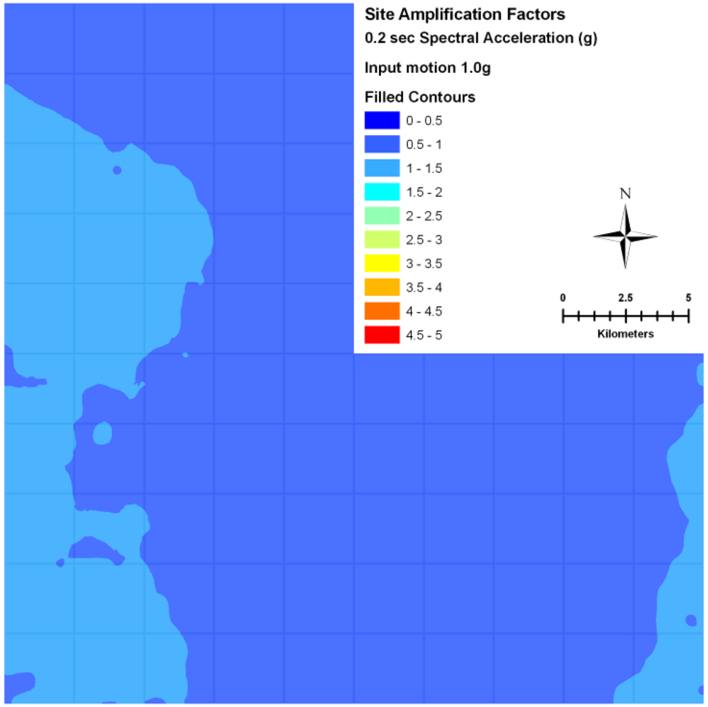

Site Amplification Factors
Peak Ground Acceleration (g)
Input motion 1.0g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

0.2 sec SA

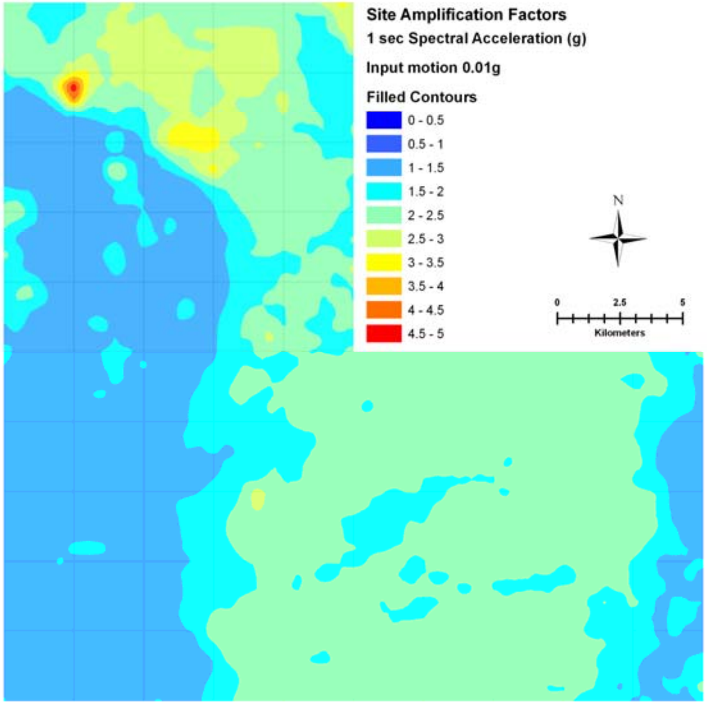

Site Amplification Factors
0.2 sec Spectral Acceleration (g)
Input motion 0.01g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

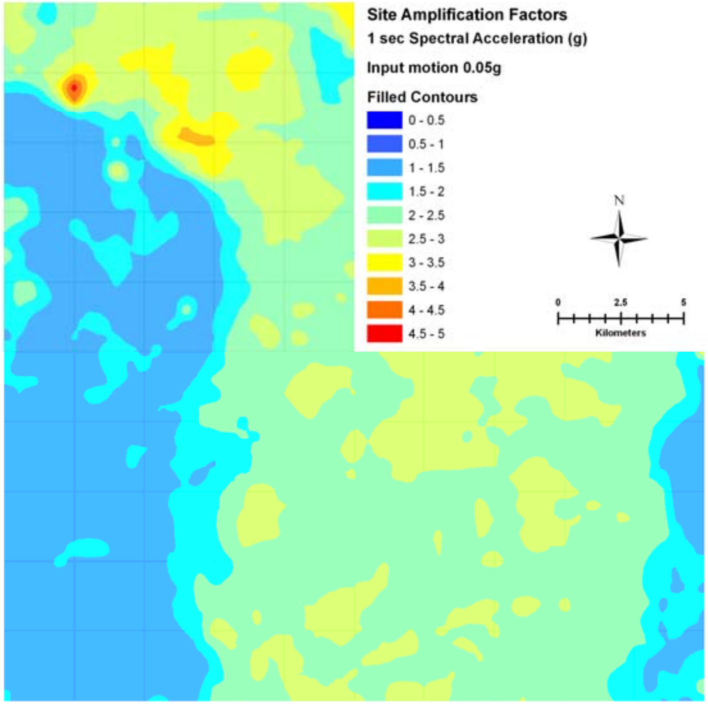

Site Amplification Factors
0.2 sec Spectral Acceleration (g)
Input motion 0.05g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

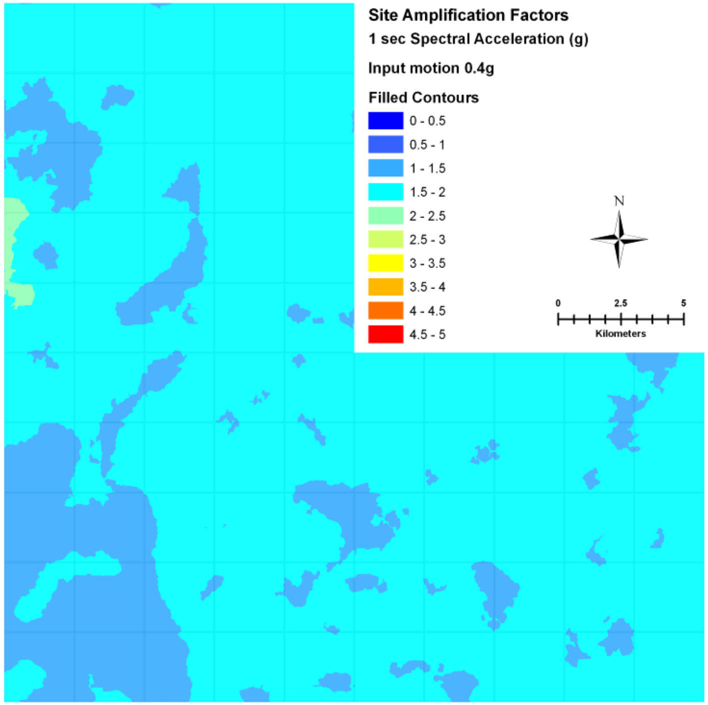

Site Amplification Factors
0.2 sec Spectral Acceleration (g)
Input motion 0.4g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

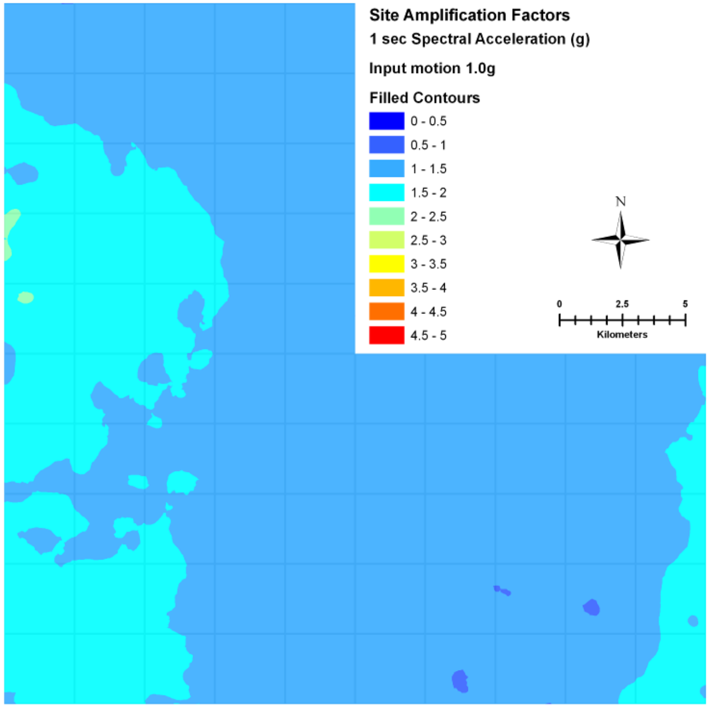

Site Amplification Factors
0.2 sec Spectral Acceleration (g)
Input motion 1.0g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

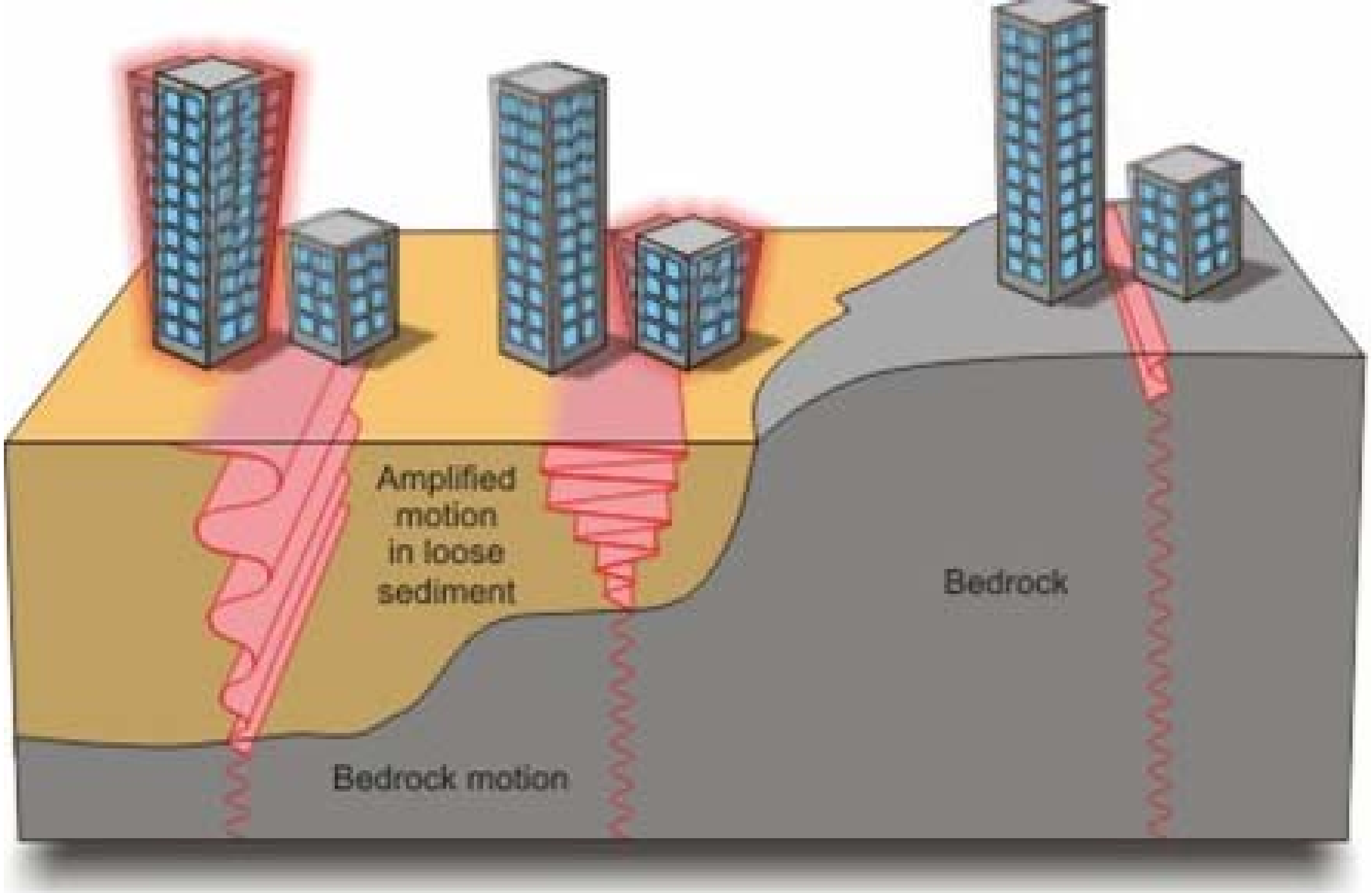
1.0 sec SA


Site Amplification Factors
1 sec Spectral Acceleration (g)
Input motion 0.01g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers


Site Amplification Factors
1 sec Spectral Acceleration (g)
Input motion 0.05g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers


Site Amplification Factors
1 sec Spectral Acceleration (g)
Input motion 0.4g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

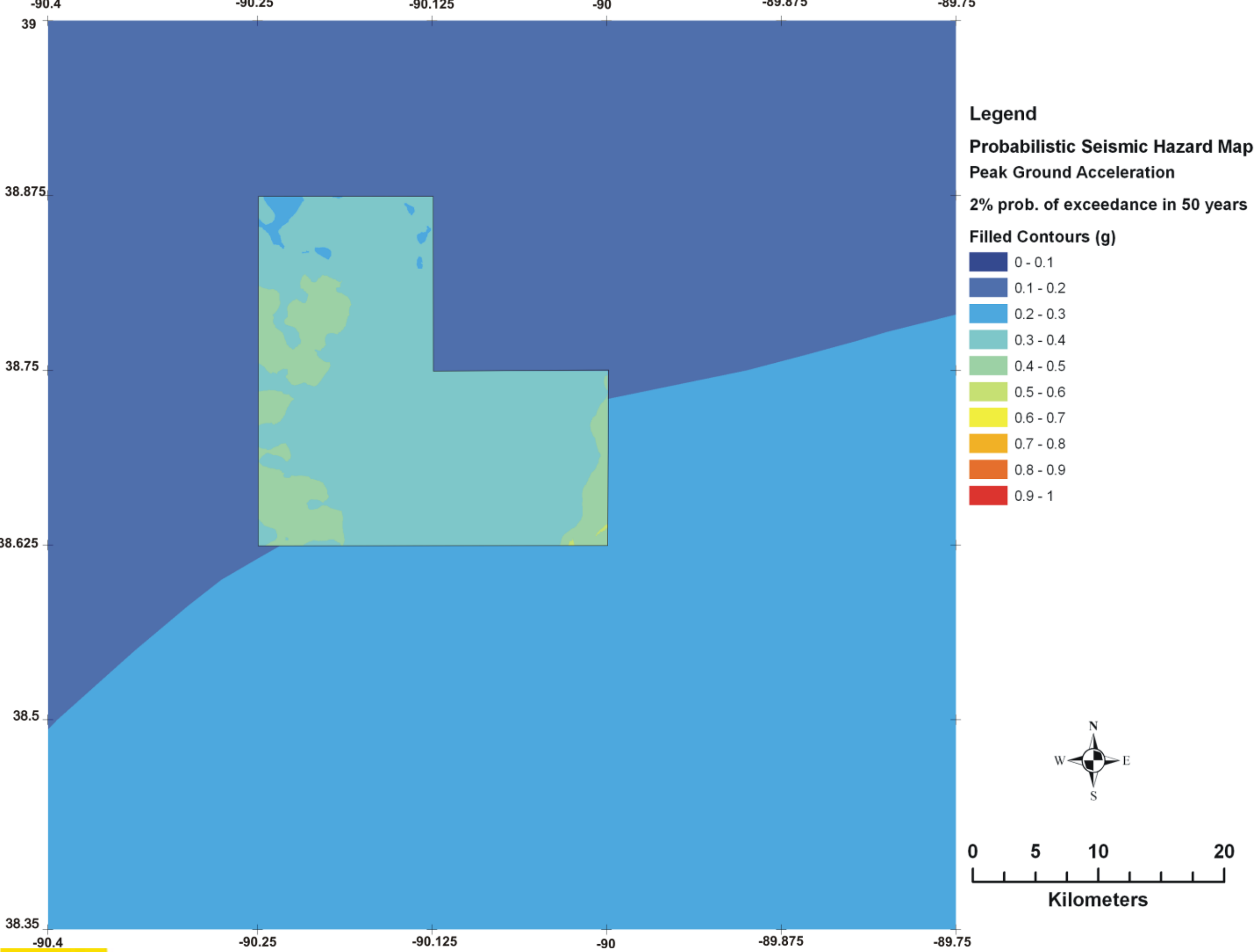

Site Amplification Factors
1 sec Spectral Acceleration (g)
Input motion 1.0g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers



- **Left – Deeper alluvial cover (~42 m) tends to magnify long period (SA 1.0 sec) motions**
- **Middle – Medium alluvial cover (~18 m) tends to magnify motions for 0.2 sec SA**
- **Right – Upland sites mantled by loess tend to magnify bedrock motion because of impedance contrast between bedrock and soil cap.**

Urban Seismic Hazard Maps (Memphis and St Louis)

- Include the effects of variations in local geology
- Are completely consistent with the national maps
- The scale is useful locally, but not intended to be site specific



- **MS&T study study vs USGS National Map (2002)**

As much as 300% greater accelerations in loess

As much as 200% greater accelerations in alluvium

PGA (g)		Alluvium	Loess
2%-in-50	Max	0.383	0.547
	Min	0.267	0.245
	Mean	0.333	0.423

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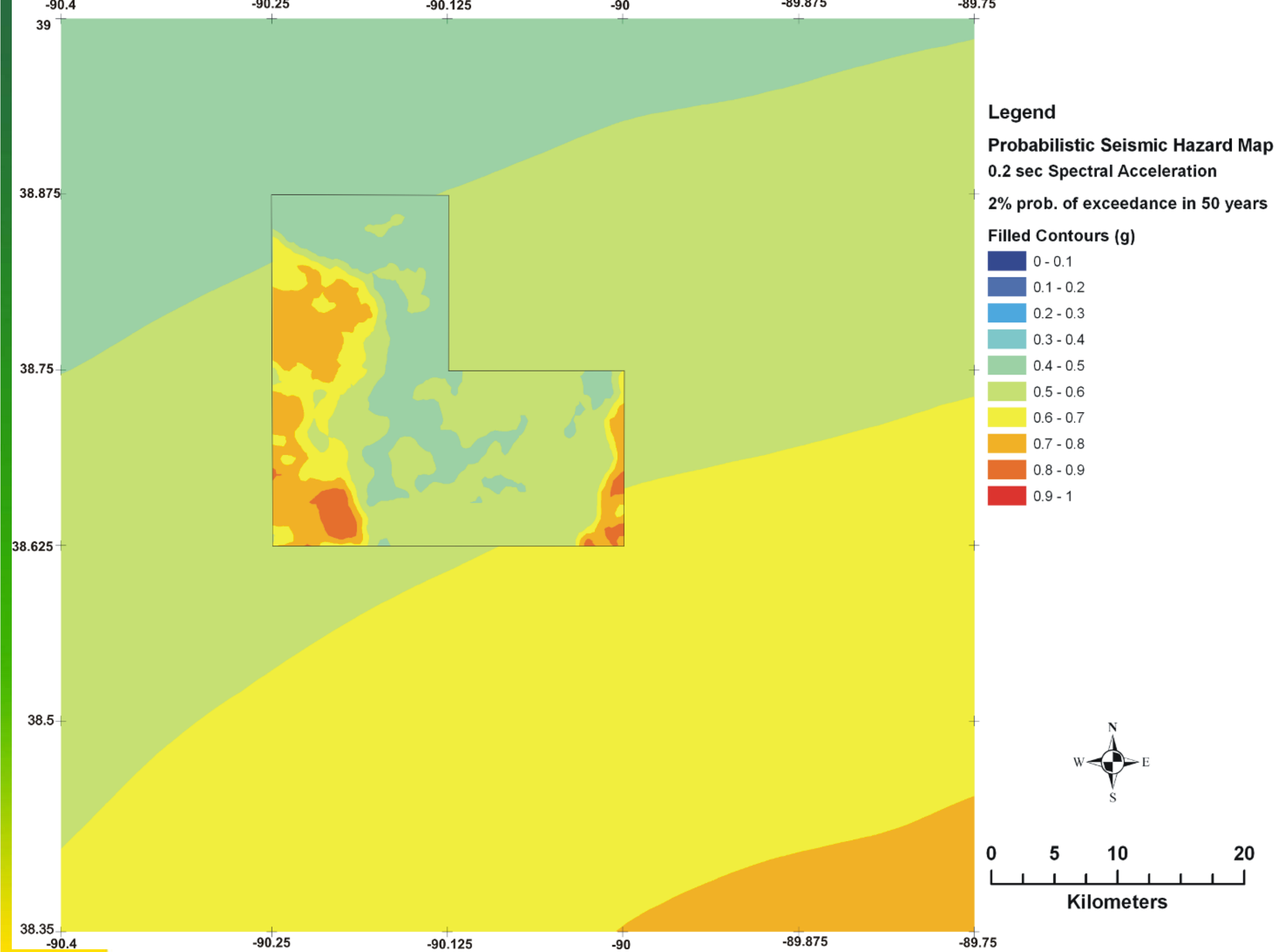


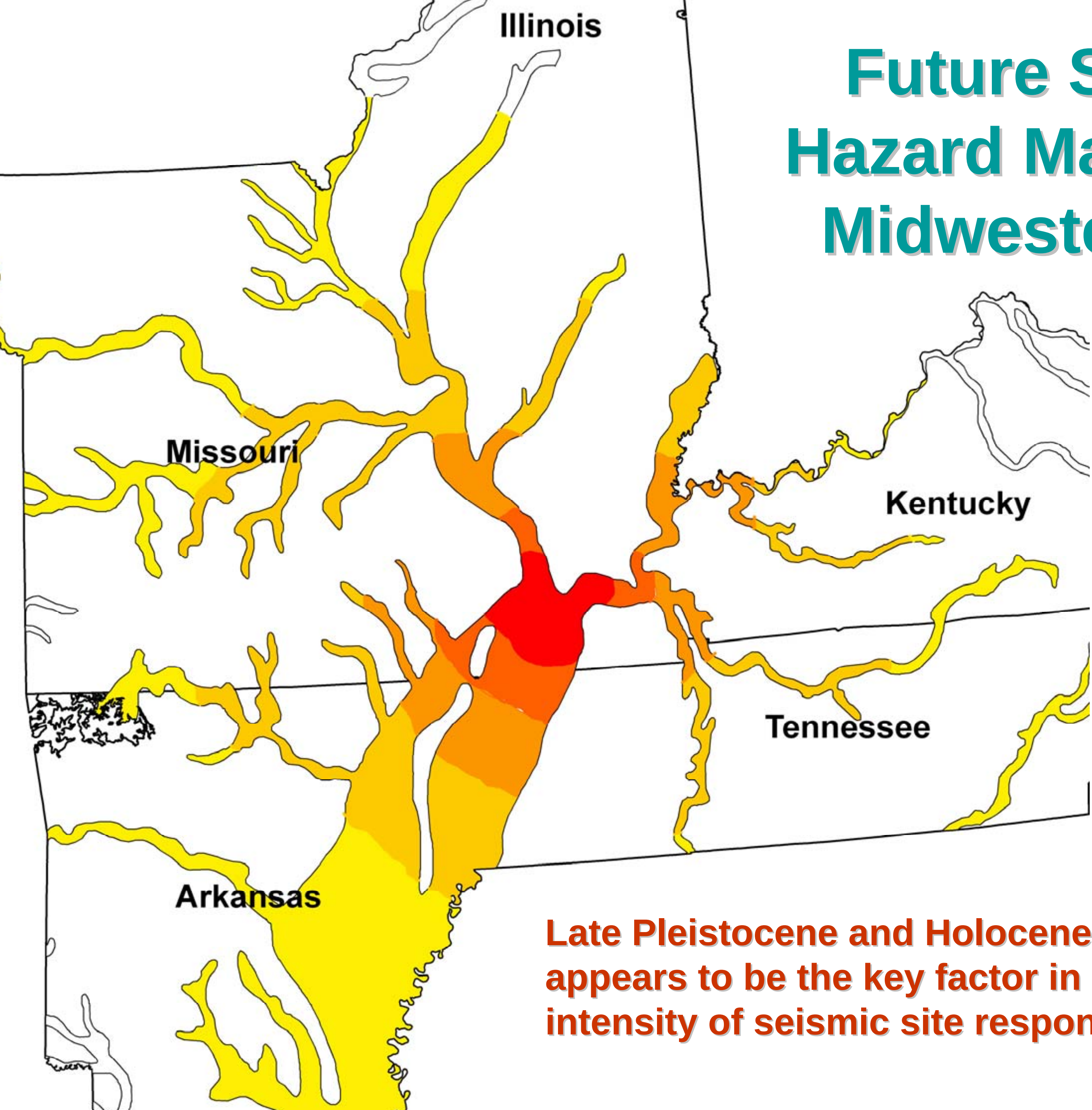
- **MS&T study vs. USGS National Map (2002)**

As much as 200% greater accelerations in loess

As much as 20% lower accelerations in alluvium, locally.

0.2 sec SA		Alluvium	Loess
2%-in-50	Max	0.783	0.965
	Min	0.407	0.422
	Mean	0.511	0.750

Future Seismic Hazard Map for the Midwestern USA



Late Pleistocene and Holocene Alluvial thickness appears to be the key factor in controlling local intensity of seismic site response