“Earthquakes: Mean Business”

Outreach Event for Business and Industry
Friday, February 1, 2008
St Louis, Missouri

Earthquakes:
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February 1, 2008

Update on Pilot Program to Assess Seismic Hazards in the St. Louis Metro Area

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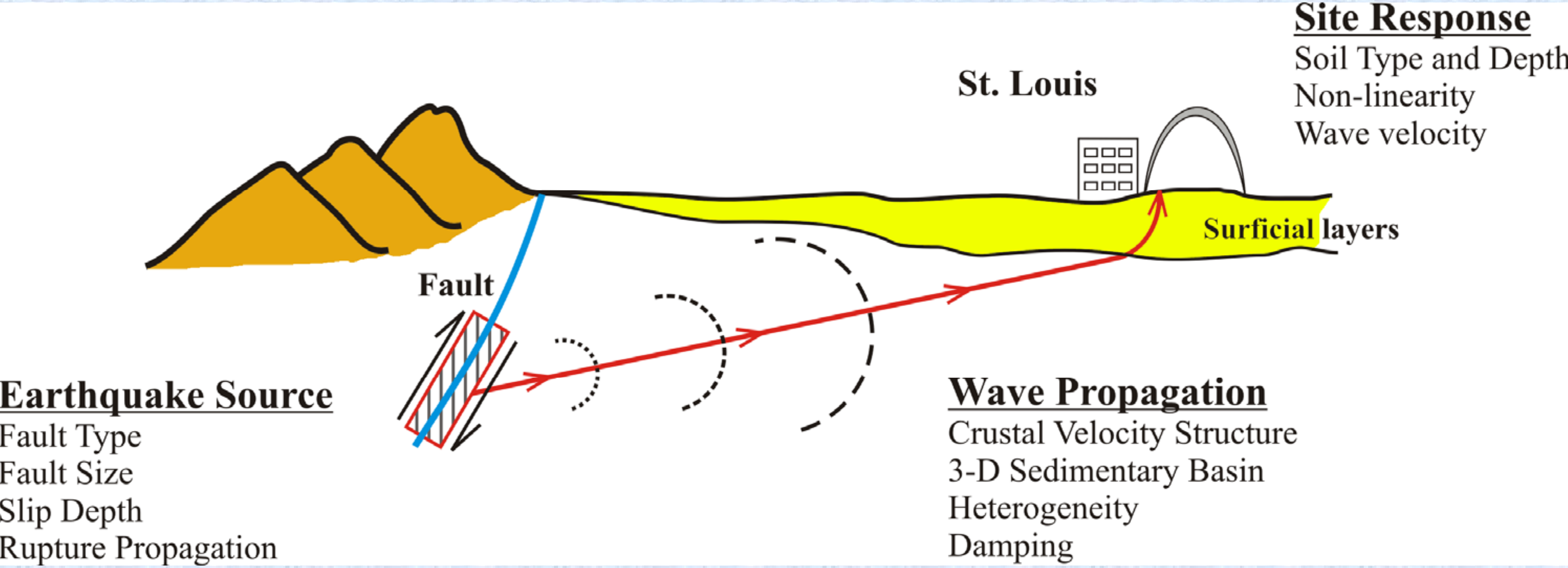
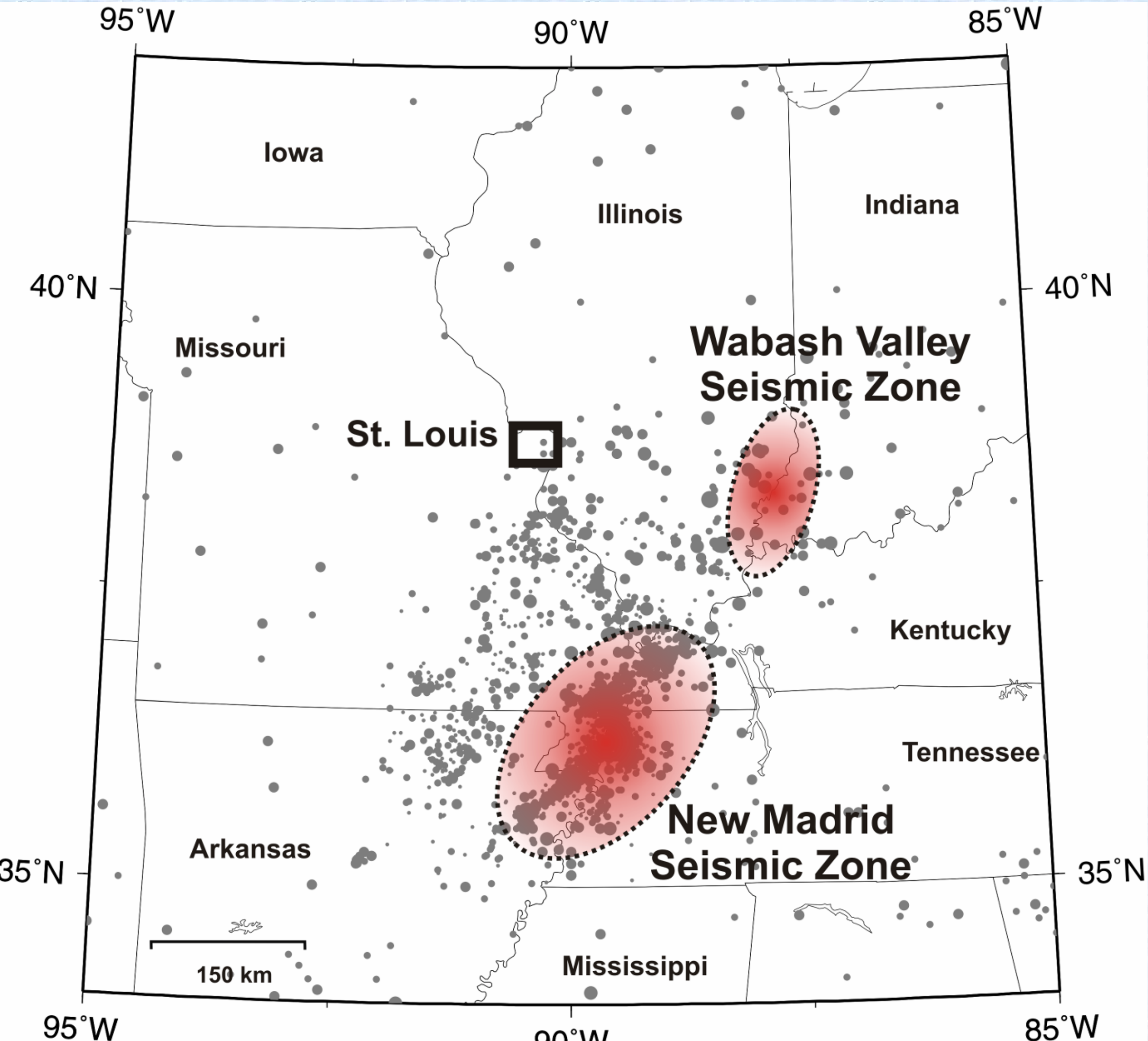
Seismic Hazard Analysis Requires an appreciation of three effects:

- **Source, Path, and Site Effects**



Central United States Earthquakes



New Madrid Events

Sediments show repeat events occurred about :

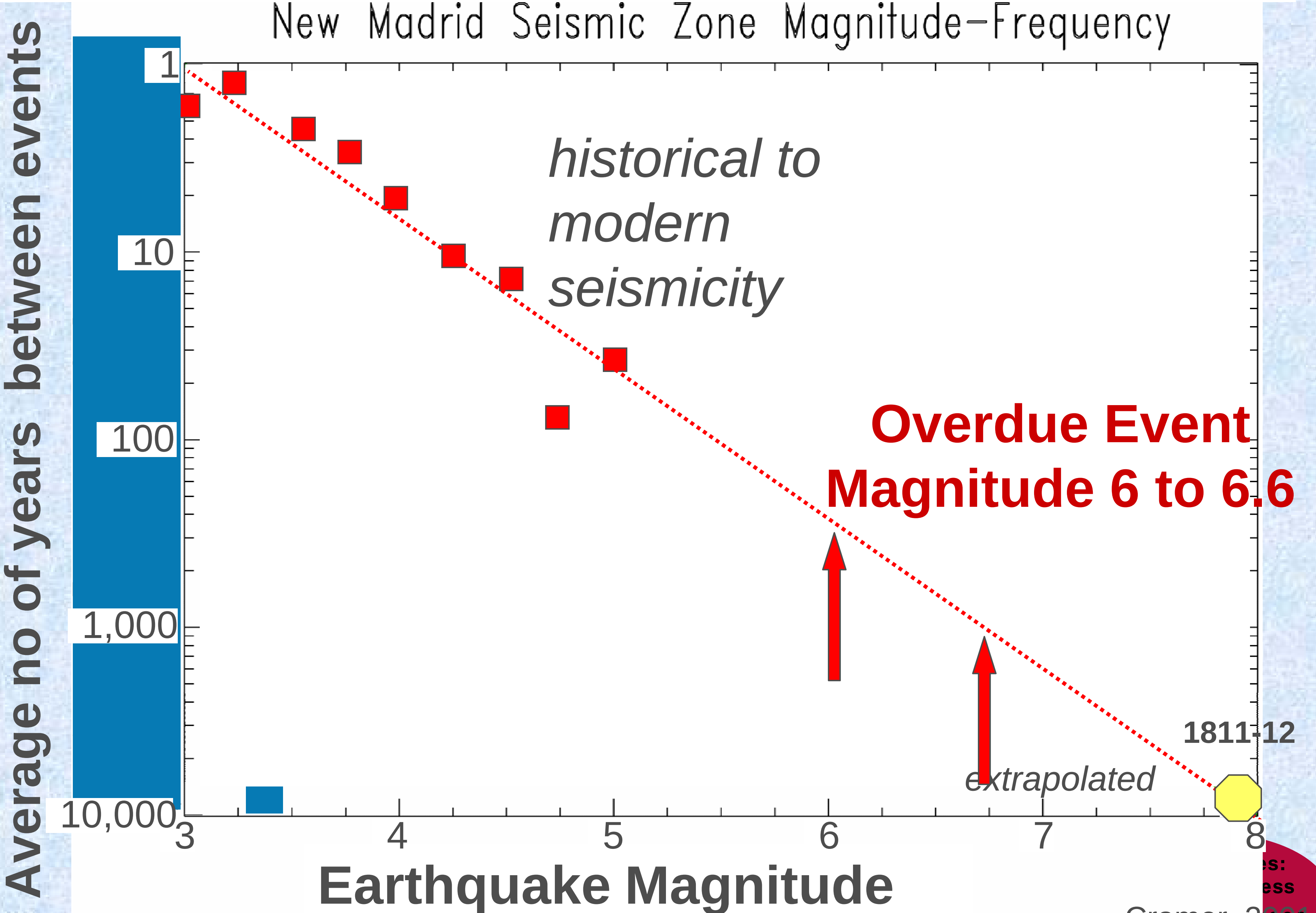
- 200 years ago (1811-1812)
- 550 years ago
- 1,100 years ago
- 1,700 years ago

Wabash Valley Area

Large earthquakes recorded in sediments, occurred about:

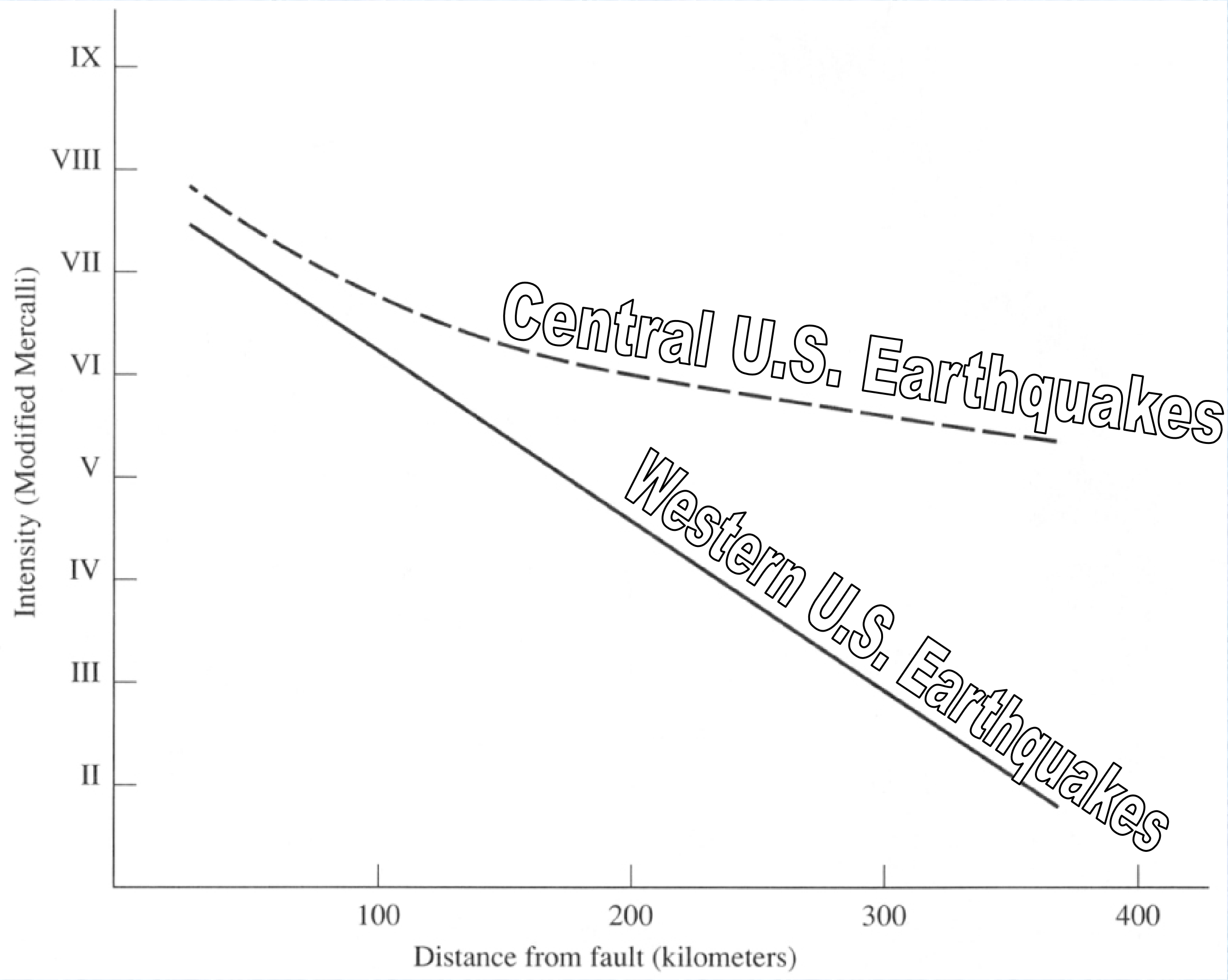
- 2,000 years ago – M 6.2
- 4,000 years ago – M 6.3
- 6,100 years ago – M 7.1
- 12,000 years ago – M 6.6
- 20,000 years ago

Source Effects-New Madrid Magnitude *vs.* Frequency



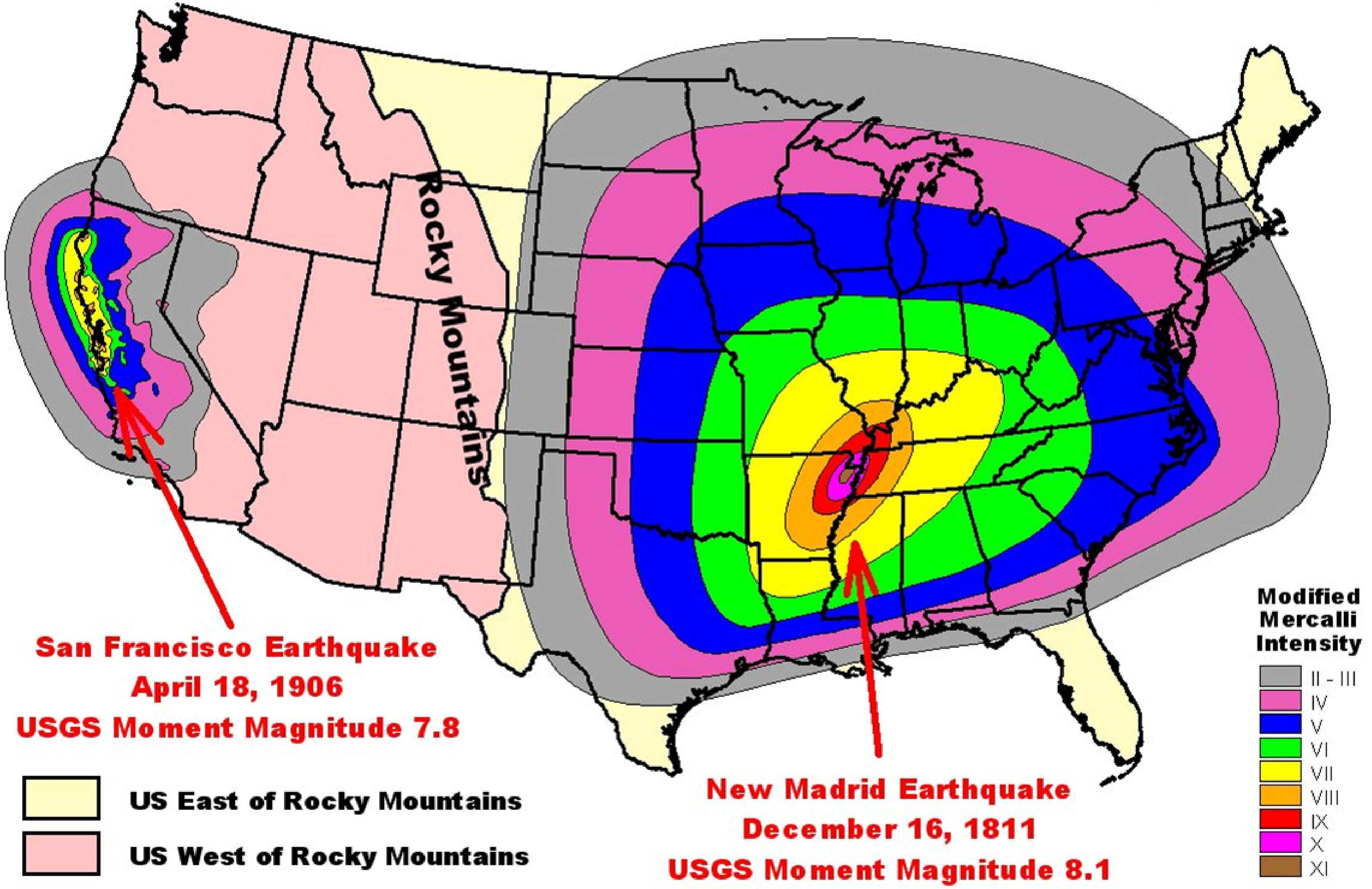
2. Path Effects

How does the energy and the shaking frequency change along its travel path?

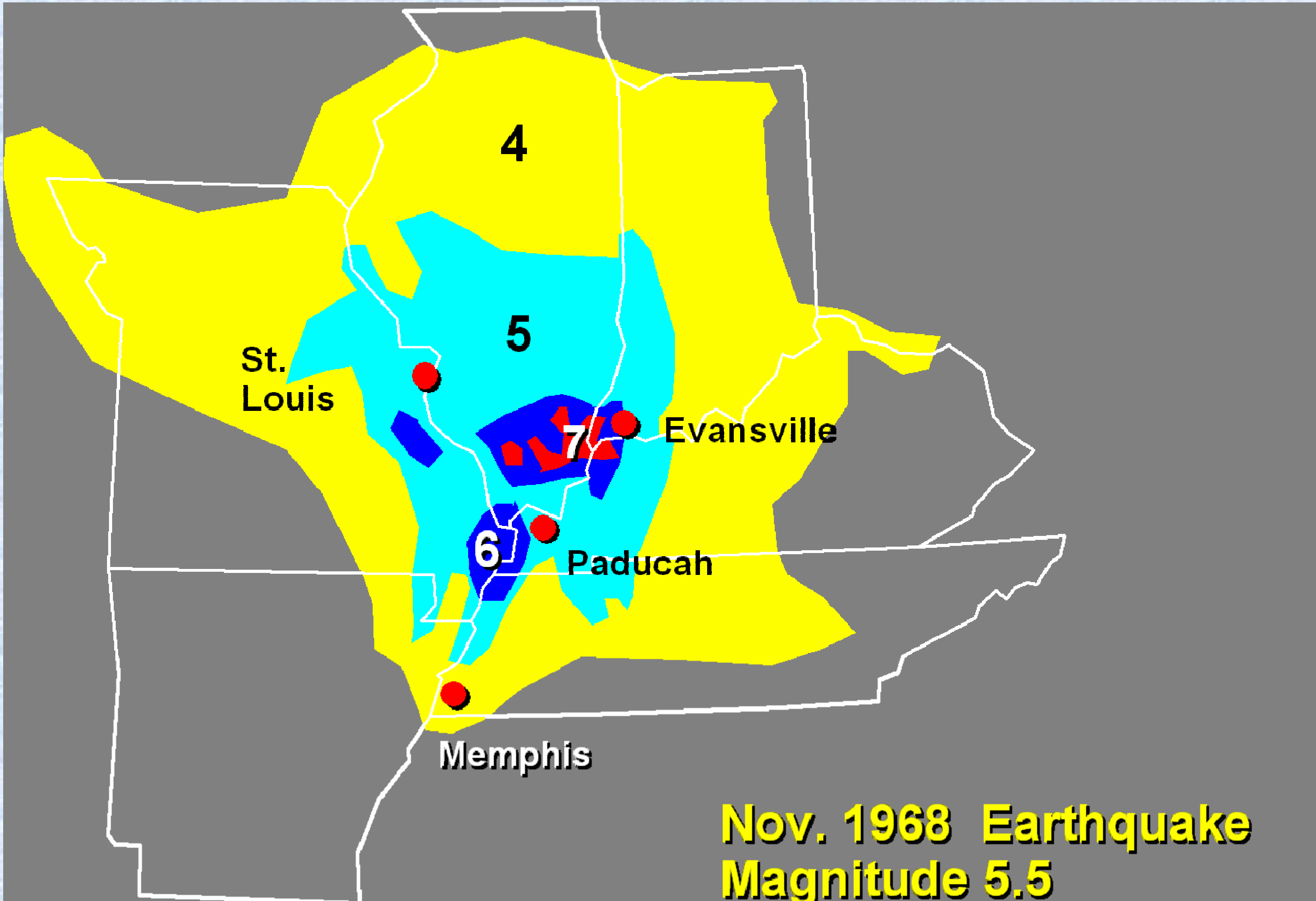


SHAKING INTENSITY versus DISTANCE

Midwest quakes are less frequent, but much more lethal than California quakes because there is <u>less damping</u> of seismic energy in the basement rocks.


Rocky Mountains
San Francisco Earthquake
April 18, 1906
USGS Moment Magnitude 7.8
New Madrid Earthquake
December 16, 1811
USGS Moment Magnitude 8.1
Modified Mercalli Intensity
II - III
IV
V
VI
VII
VIII
IX
X
XI
US East of Rocky Mountains
US West of Rocky Mountains

Nov 1968 Earthquake WVSZ M 5.5



Source: ISGS (Robert Bauer)

Damage in St. Louis from 1968 quake 177 km (110 miles) away from the epicenter

- Boy injured by a falling chimney –found unconscious
- 30 reports of fallen chimneys
- Several reports of damaged/fallen walls

Source: ISGS (Robert Bauer)

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

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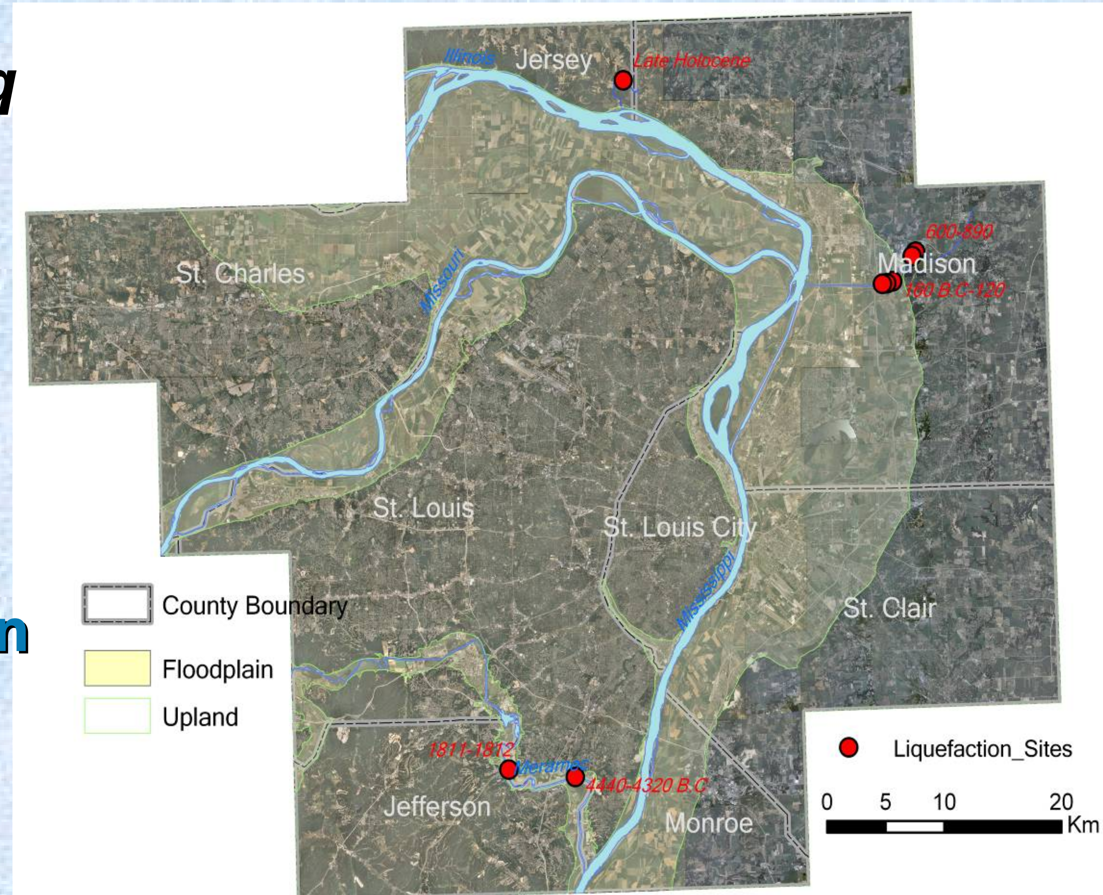
The St Louis study area consists of 29 USGS 7.5 minute Quadrangles in *Missouri* and *Illinois*, *encompassing 4,482 sq km land area*

The area consists of: floodplains along the rivers; and loess-covered elevated uplands on either side.

Earthquake liquefaction features have been identified along the major river channels; some are interpreted as having formed in *1811-1812*.



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

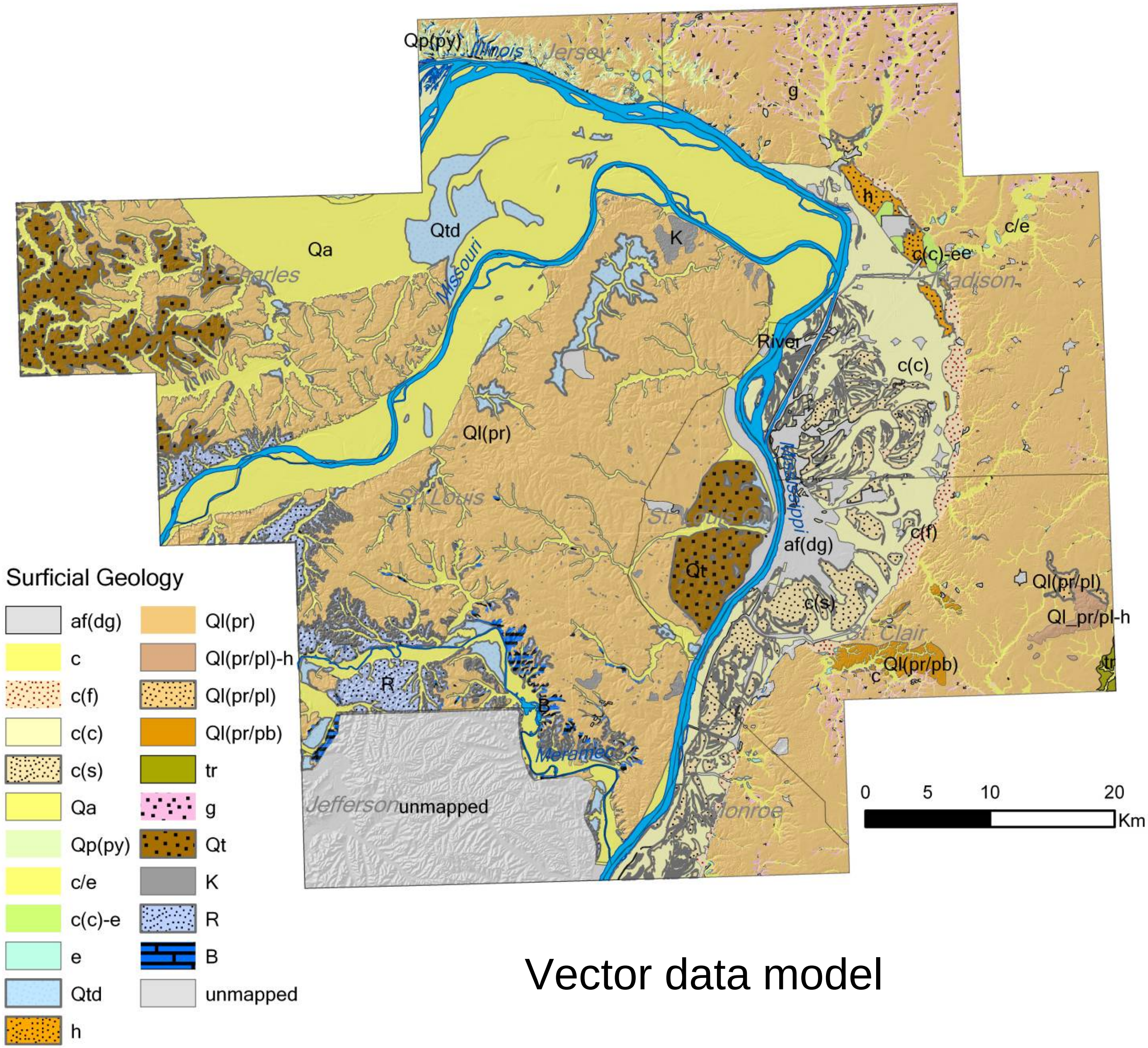
We collected and/or estimated the following information:

- 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

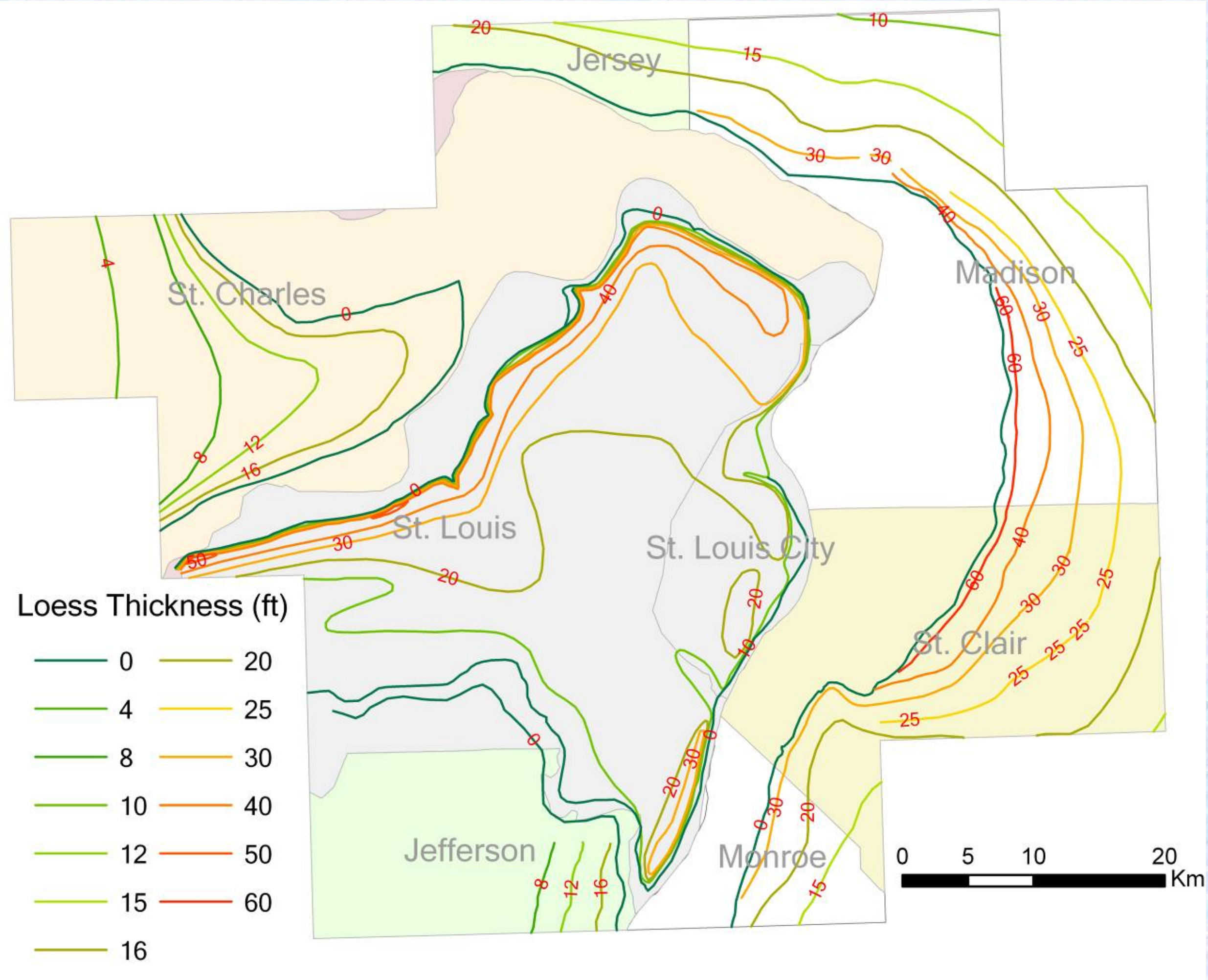
Compiled Surficial Geologic Map



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**

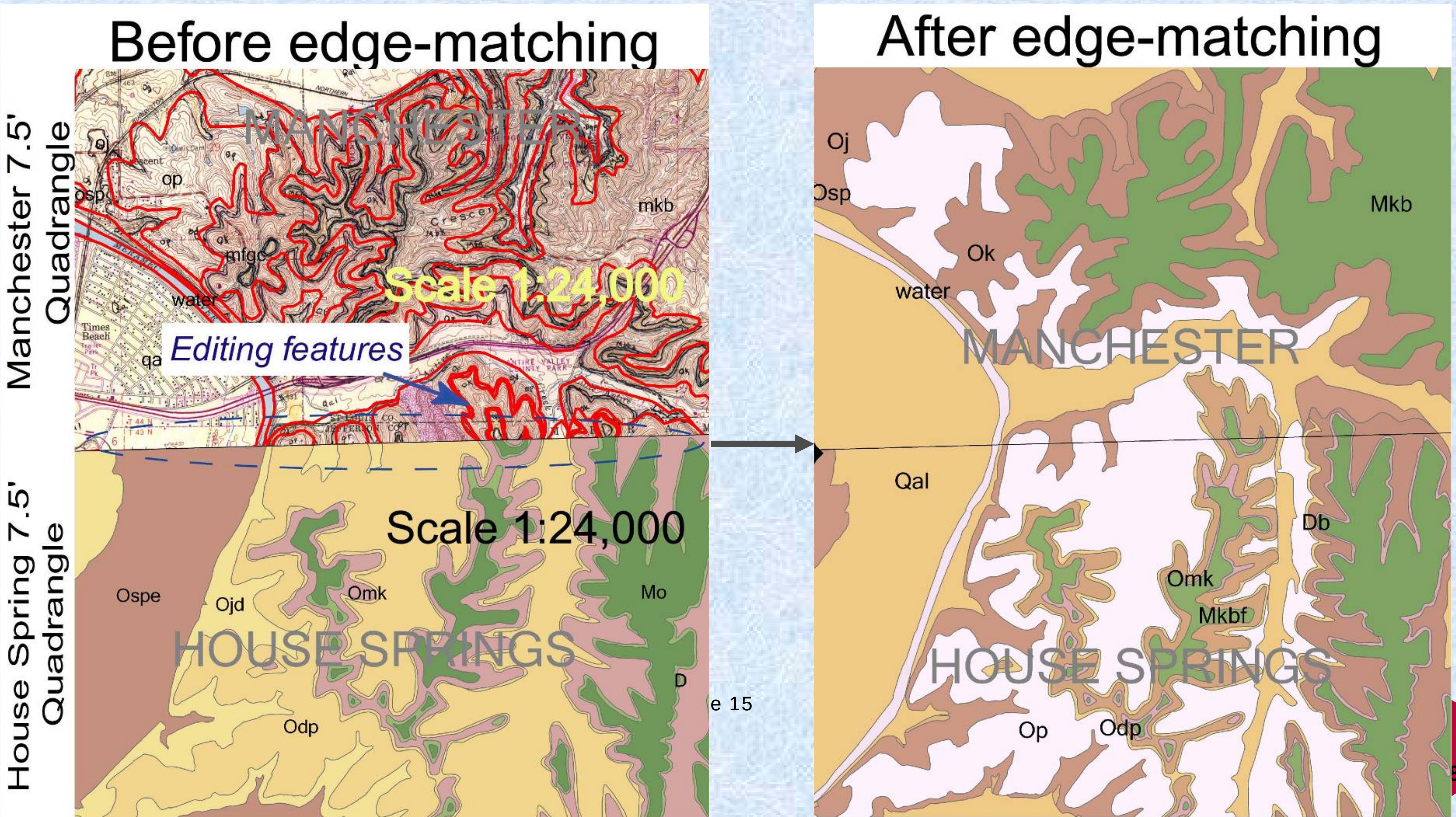


- Vector data model

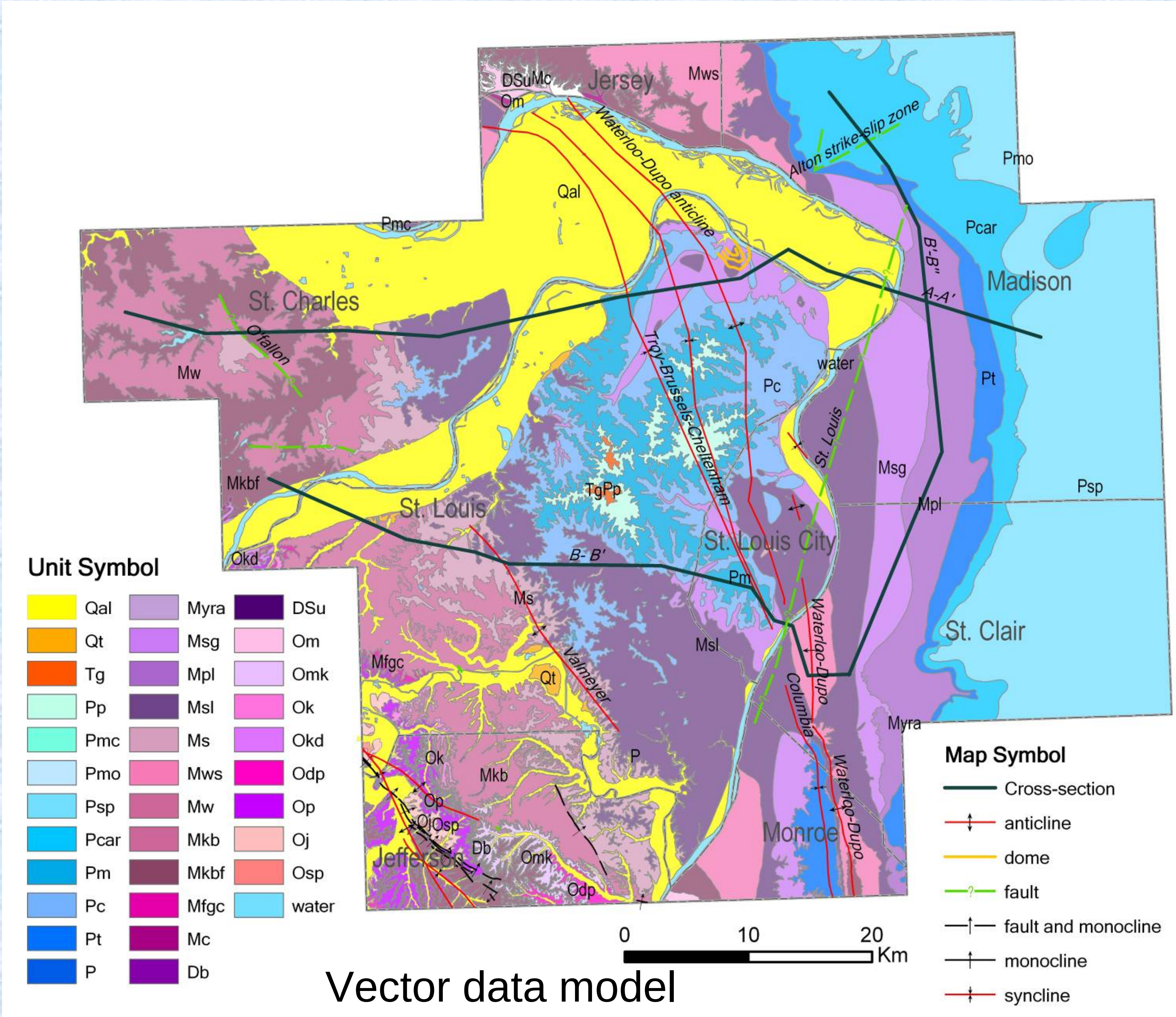
Map Scale Matching Problems

Possible Solutions:

For mismatching boundary area, editing another 24K map boundaries instead of 100K map



Compiled Bedrock Geology Map



Vector data model

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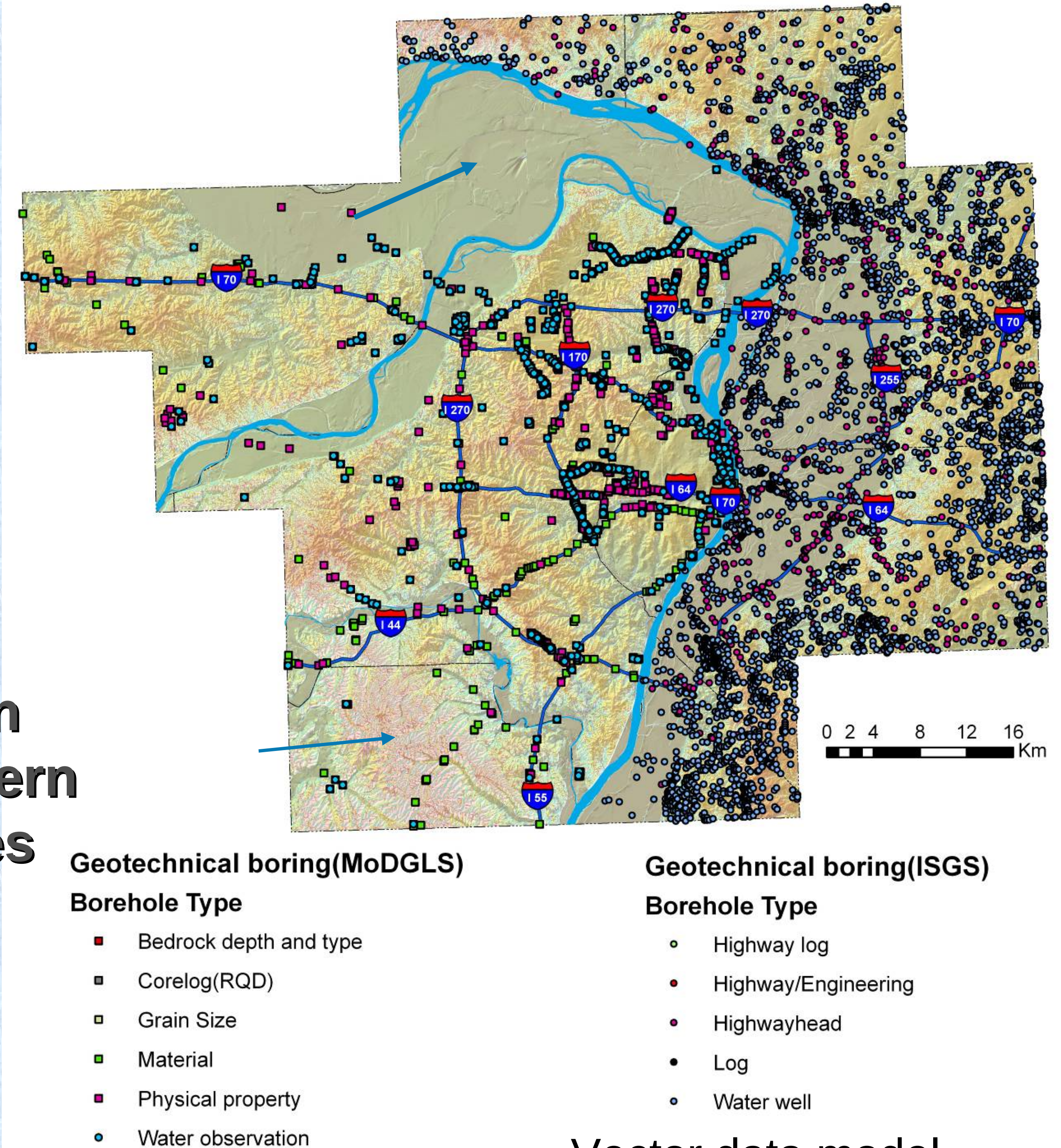
Borehole Locations

- Data Sources:
  - MoDNR-DGLS
  - ISGS

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



Vector data model

Borehole Information

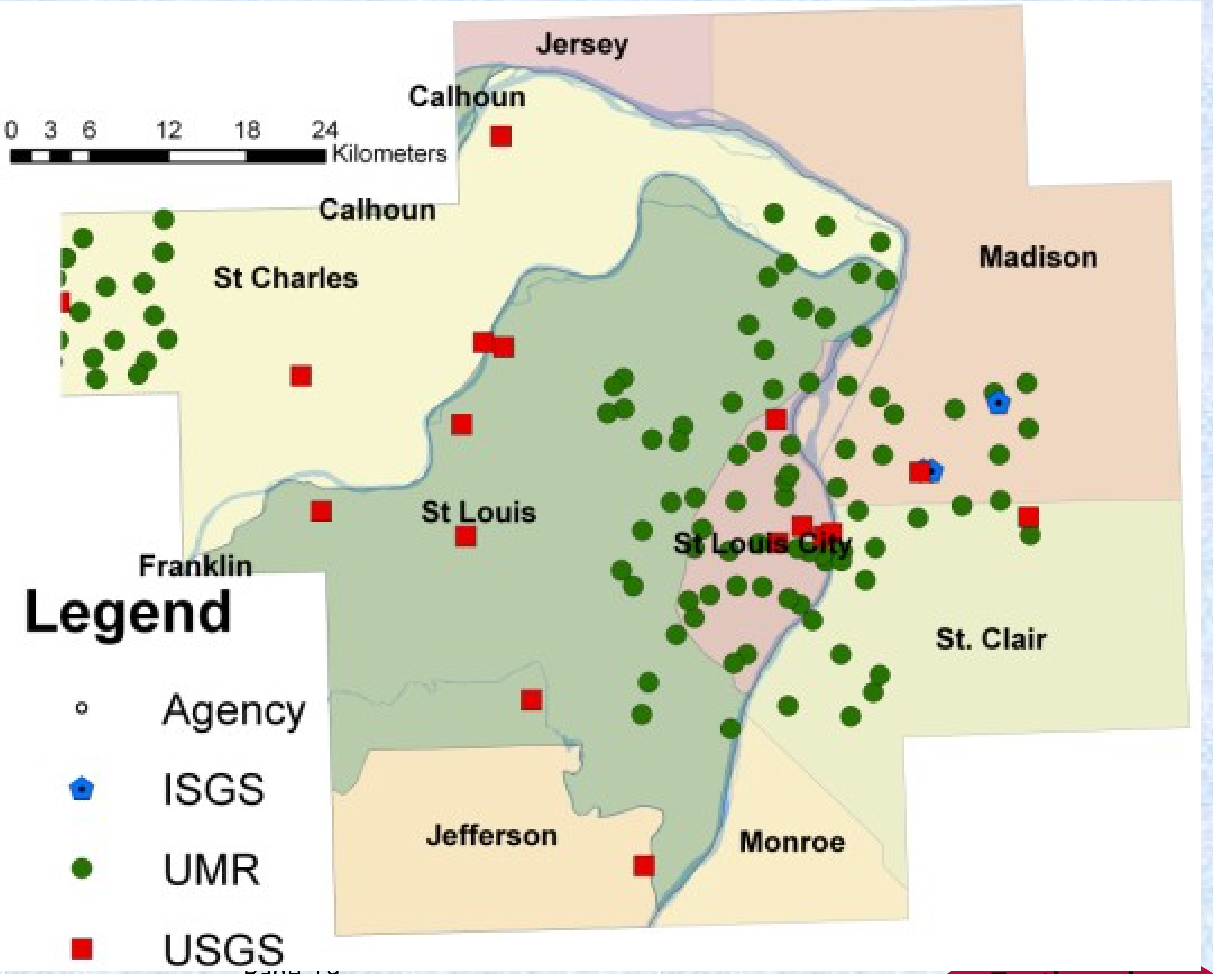
- **Data Sources (Digital Format); MoDNR-DGLS and ISGS**

State	Borehole type	Number of records	Item
Missouri	Bedrock	2338	Depth to bedrock, Bedrock type
	Corelog	729	Core recovery (%), Rock Quality Designation (RQD)
	Grain Size	93	Grain size anaysis of soil
	Material	2330	Description of soil material
	Physical Property	1906	Standard Penetration Test (SPT) N-value, Cone Penetration Test (CPT), ASTM class, Unit weight (water content,%), Liquid limits, and Plastic index
	Water Observation	961	Depth to groundwater
	Site	2394	
Illinois	Highway Log	857	Description of soil material
	Highway Engineering	496	Standard Penetration Test (SPT) N-value
	Highway Head	2226	Description of geotechnical boring
	Log	3636	Description of soil material
	Water Well	4728	Description of water well
	Site	4817	

Locations of Shear Wave Velocity (Vs) Measurements

Data Sources (119):

- ISGS (3)
- UMR (99)
- USGS (17)



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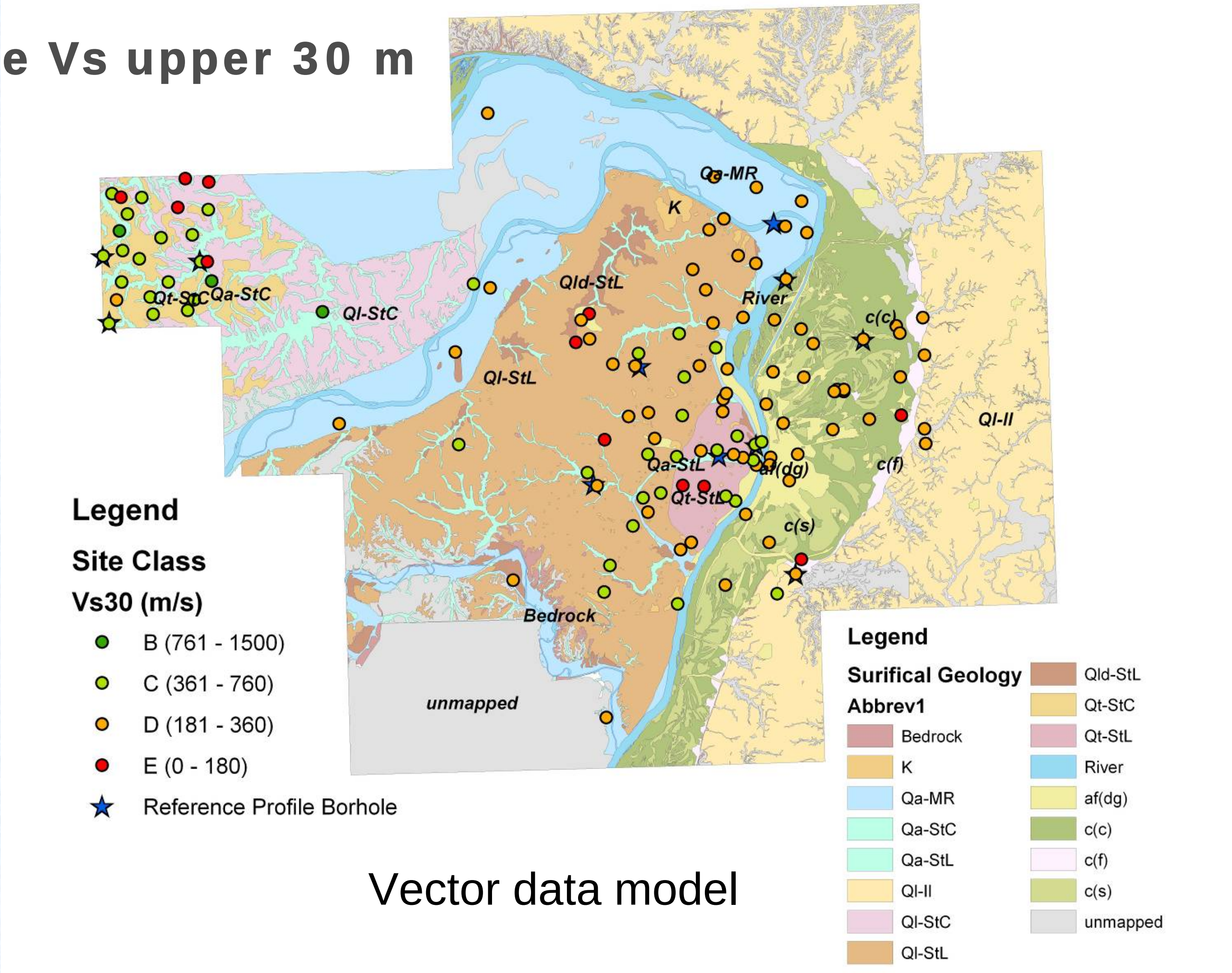
Vs_{30m} and NEHRP Soil Classes

- 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

Shear Wave Velocity (Vs) and NEHRP Soil Classes overlain on Surficial Geology Map

Vs_{30m} = average Vs upper 30 m



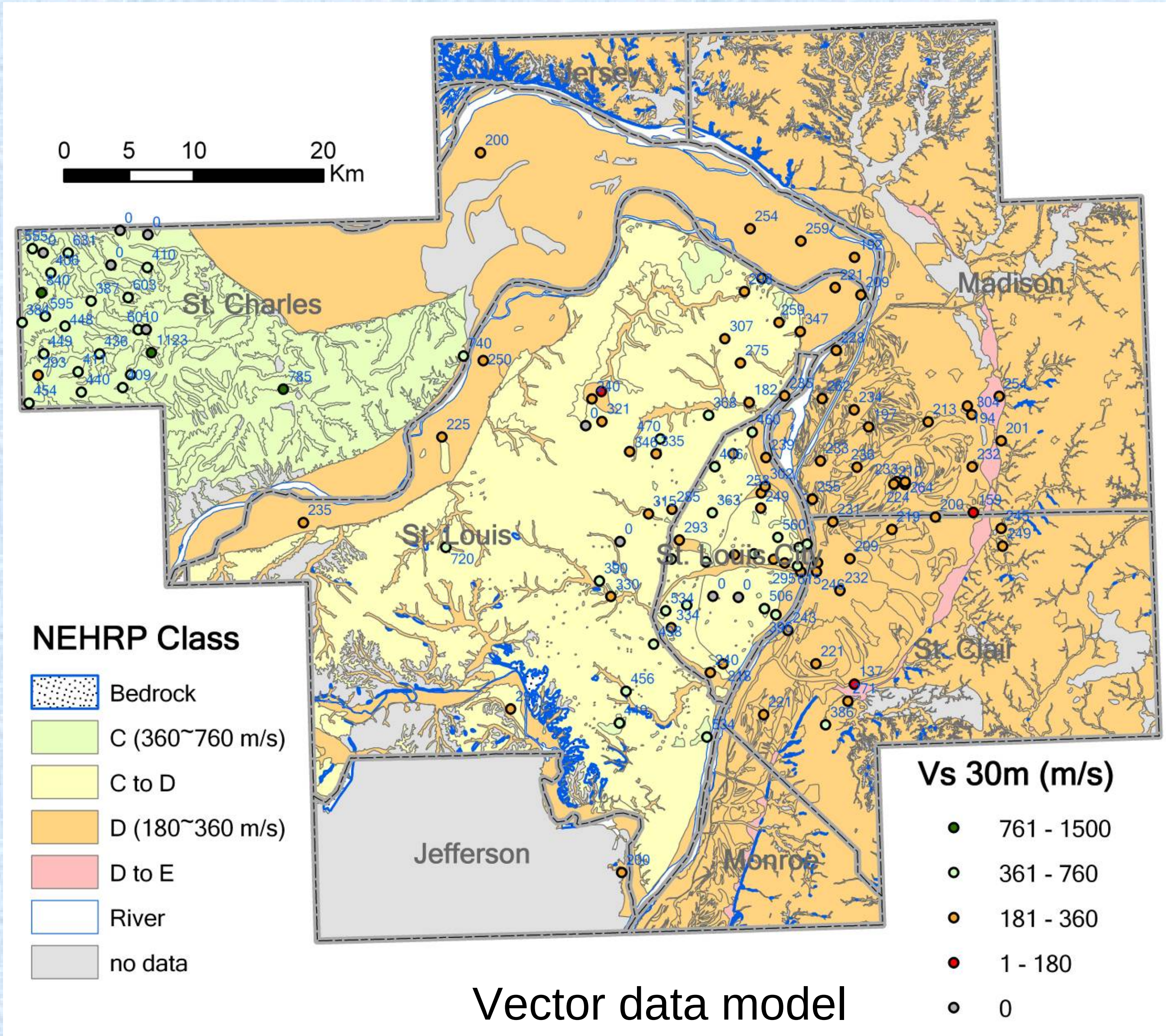
Vector data model

Mean Vs_{30m} (m/s) by Geologic Units and NEHRP Soil Type

Surficial Geologic Unit			Vs[30] (m/s)					NEHRP Class	
Material	Location	Symbol	Site count	Range	Median	Mean	Standard deviation	Site Type	% in catergory
Artificial Fill	along Mississippi River	af(dg)	14	159~620	242	277	113	D	77
Alluvium	along streams in St. Charles County	Qa-StC	3	409~454	437	433	22	C	100
	along streams in St. Louis County & City	Qa-StL	6	240~456	314	319	76	D	83
	along Major Rivers	Qa-MR	10	192~259	230	228	23	D	100
	Cahokia fan	c(f)	2	137~254	195	195	83	D to E	50/50
	Cahokia sandy	c(s)	9	197~264	221	226	24	D	100
	Cahokia clayey	c(c)	11	194~304	228	229	31	D	100
Terrace or Lake deposits	St. Louis County & City	Qld-StL	5	200~615	347	360	155	C to D	20/80
Loess	St. Charles County	Ql-StC	6	410~1123	686	715	239	C	67
	St. Louis County & City	Ql-StL	24	182~720	341	368	113	C to D	46/54
	Illinois	Ql-Il	5	201~386	249	270	69	D	80
Till	St. Charles County	Qt-StC	13	293~840	440	448	141	C	92
	St. Louis City	Qt-StL	6	218~560	292	340	130	C to D	33/64
Karst	St. Louis County & City	K	5	410~534	506	487	55	C	100

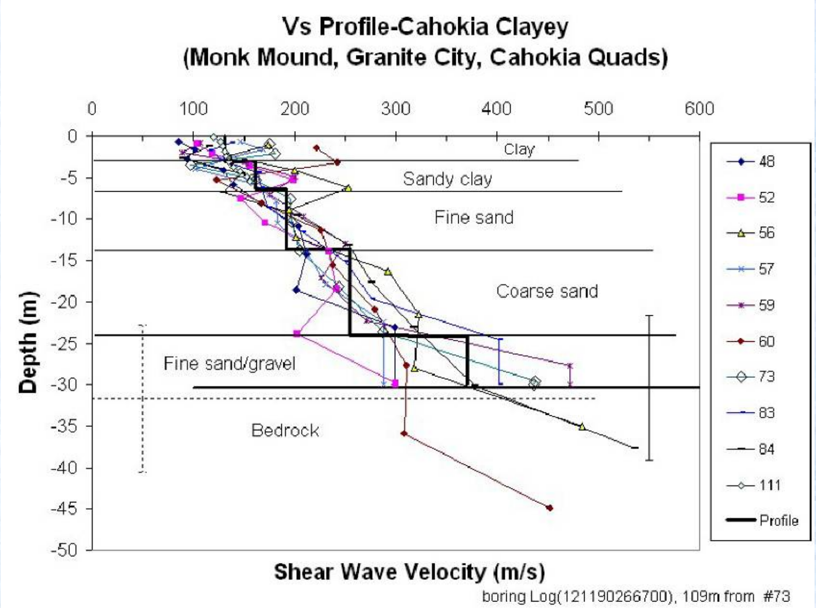
Preliminary NEHRP Soil Classification Map

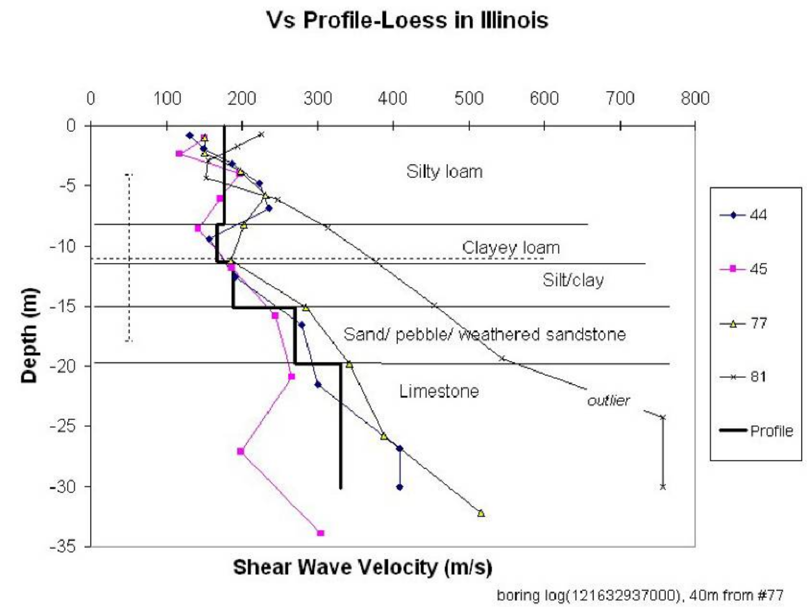
(mean Vs_{30m} / Surficial Geology)



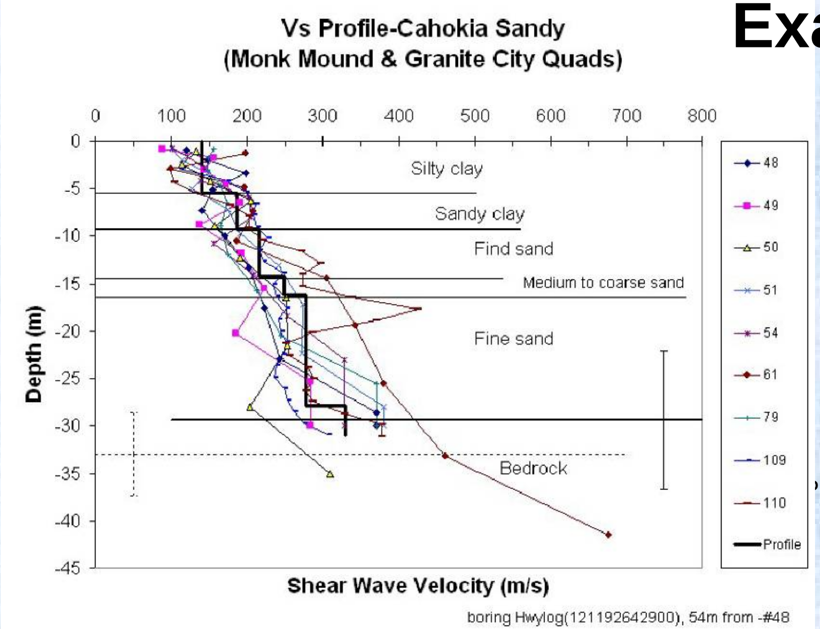
Vector data model

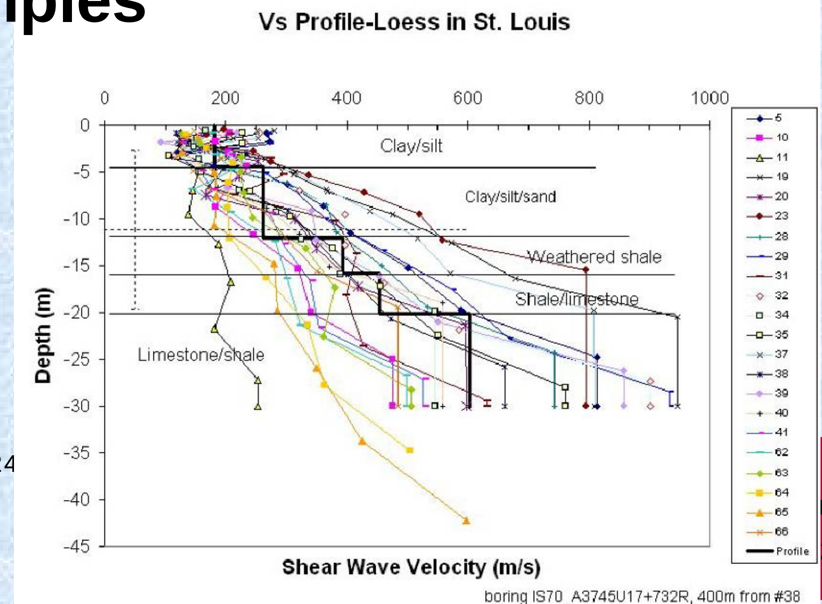
Vs Reference Profiles and Soil Columns derived from adjacent boreholes





Examples





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Geospatial Prediction of the Groundwater Table in the STL study area

Application: important consideration in engineering and environmental decision making; for

- waste disposal sites
- natural hazards, such as shaking-induced soil liquefaction and lateral spreads.

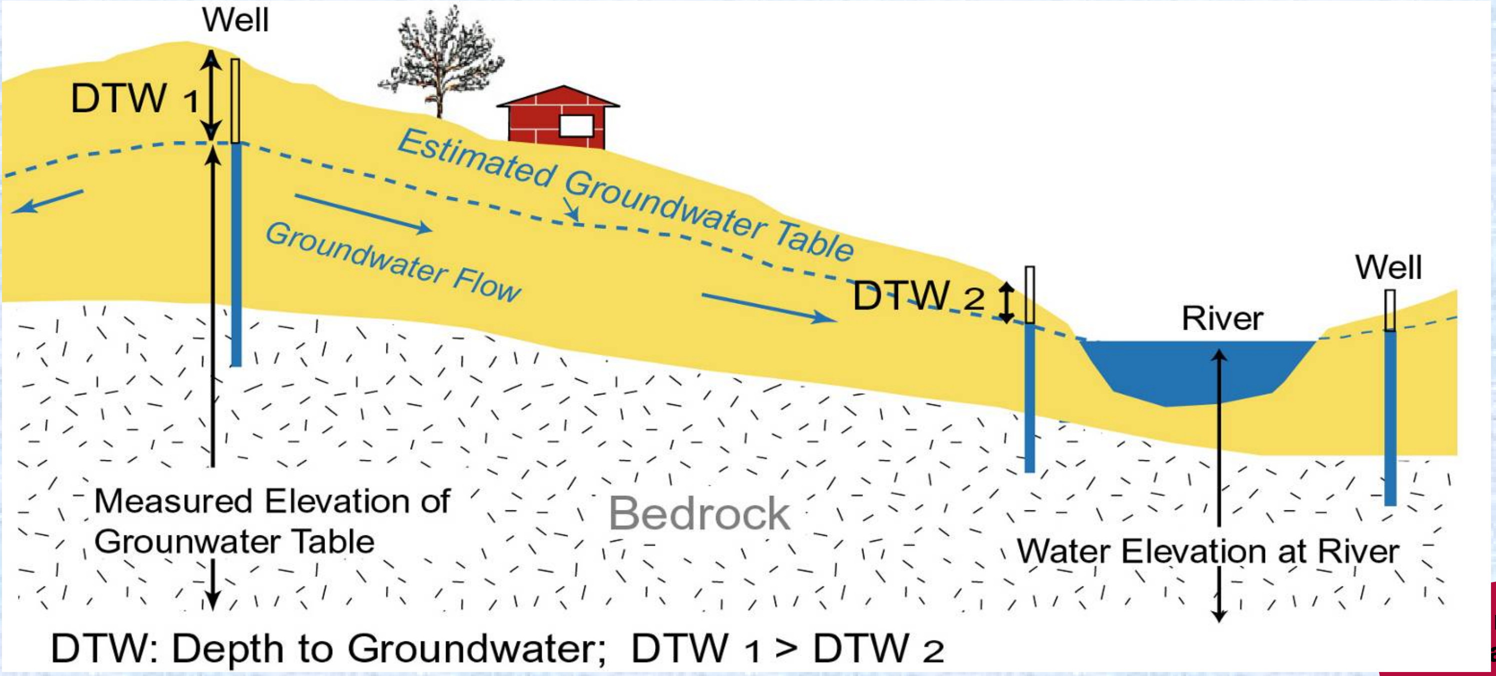
General Specifications of the Groundwater Table

The **groundwater table elevation** generally meets the following specifications:

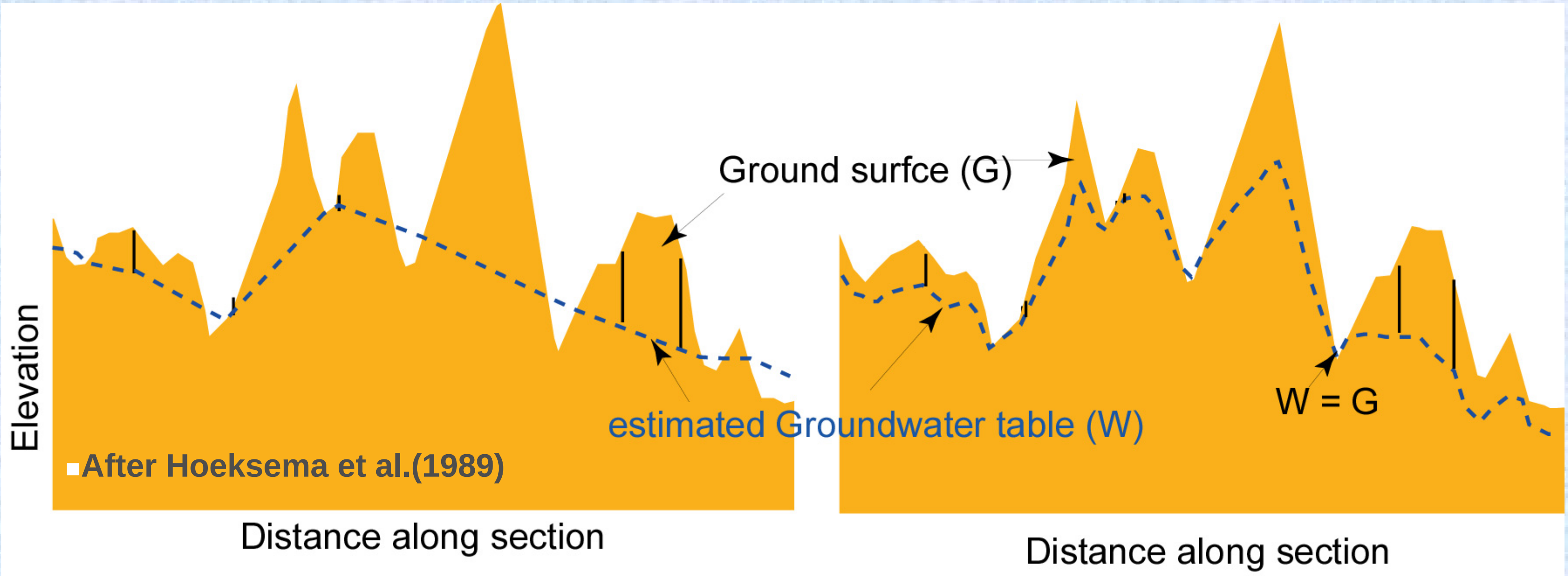
1) follows the shape of the land surface

2) is equal to the **ground elevation** at streams,

3) the depth to **groundwater table** is deepest in hilly area



Profile of Groundwater Table (W) with and without considering the ground surface (G)



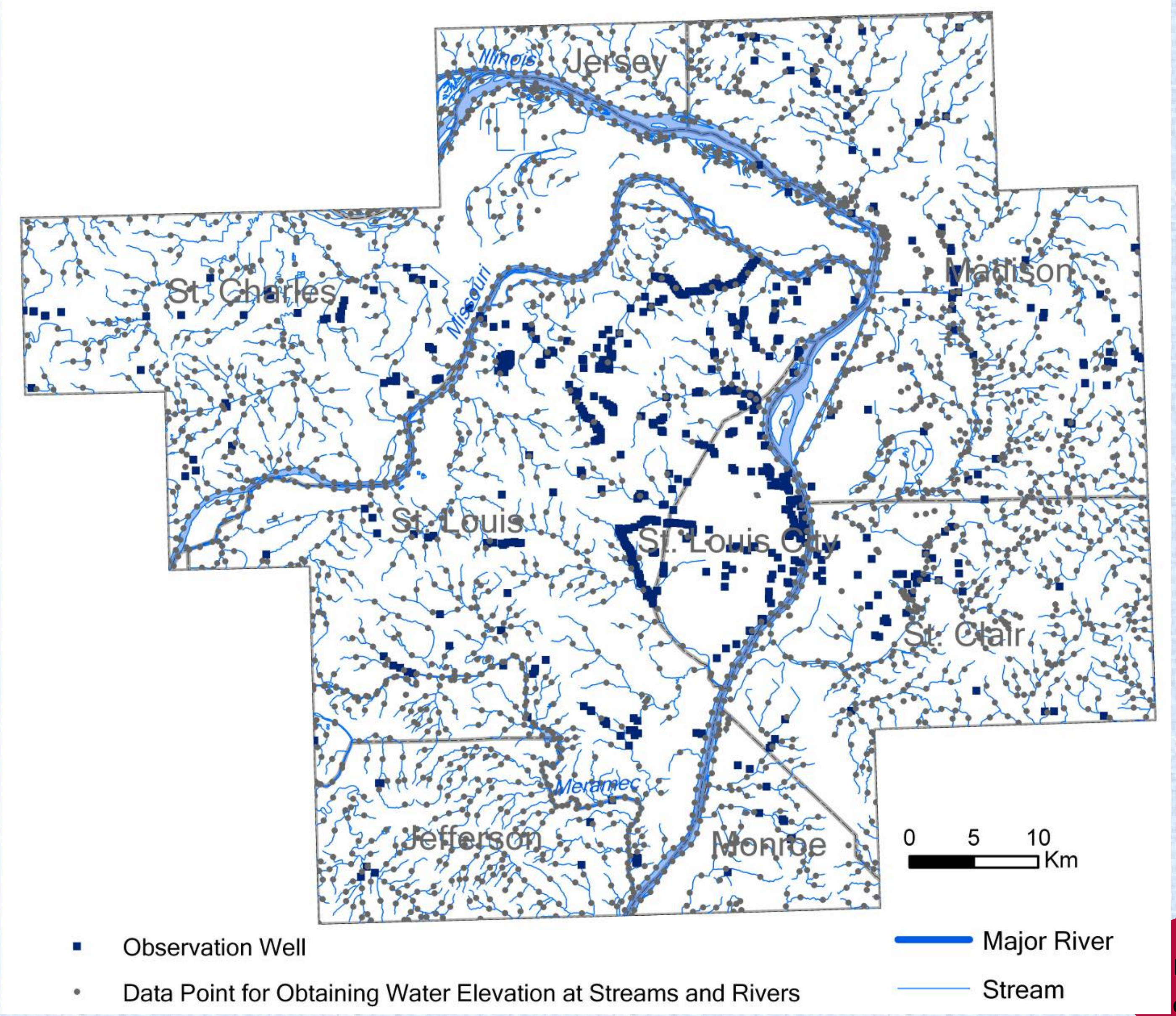
Estimated W without considering G

- Using kriging

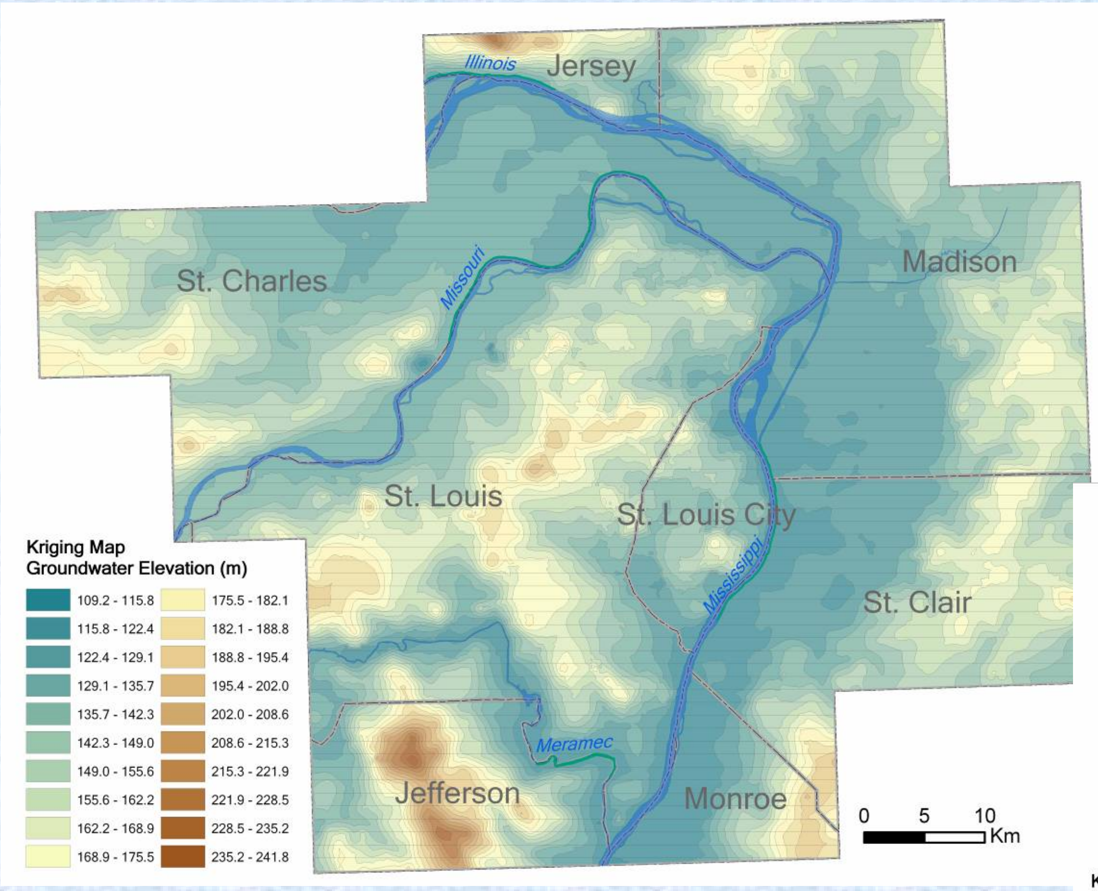
- Estimate W concerning G and constraining W=G

- Using cokriging

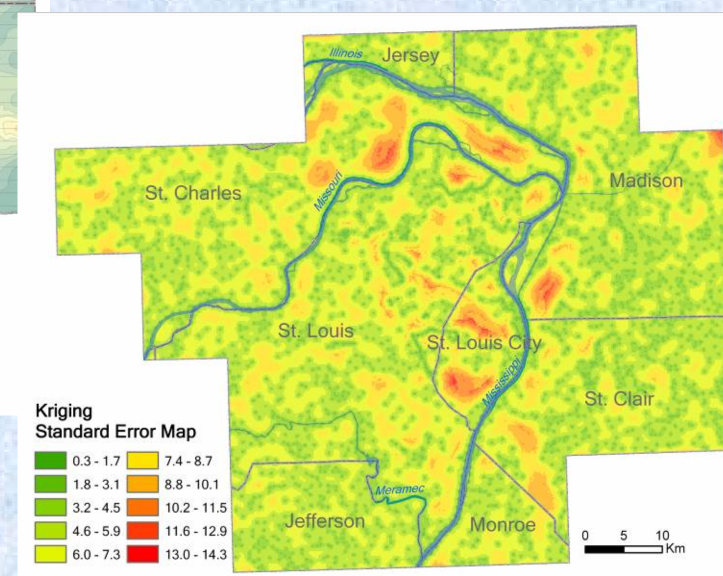
Input data for Modeling Groundwater Table



Kriging Map of Groundwater Table Elevation



Standard Error Map Using Kriging



- Raster data model

Cokriging Map of Groundwater Table

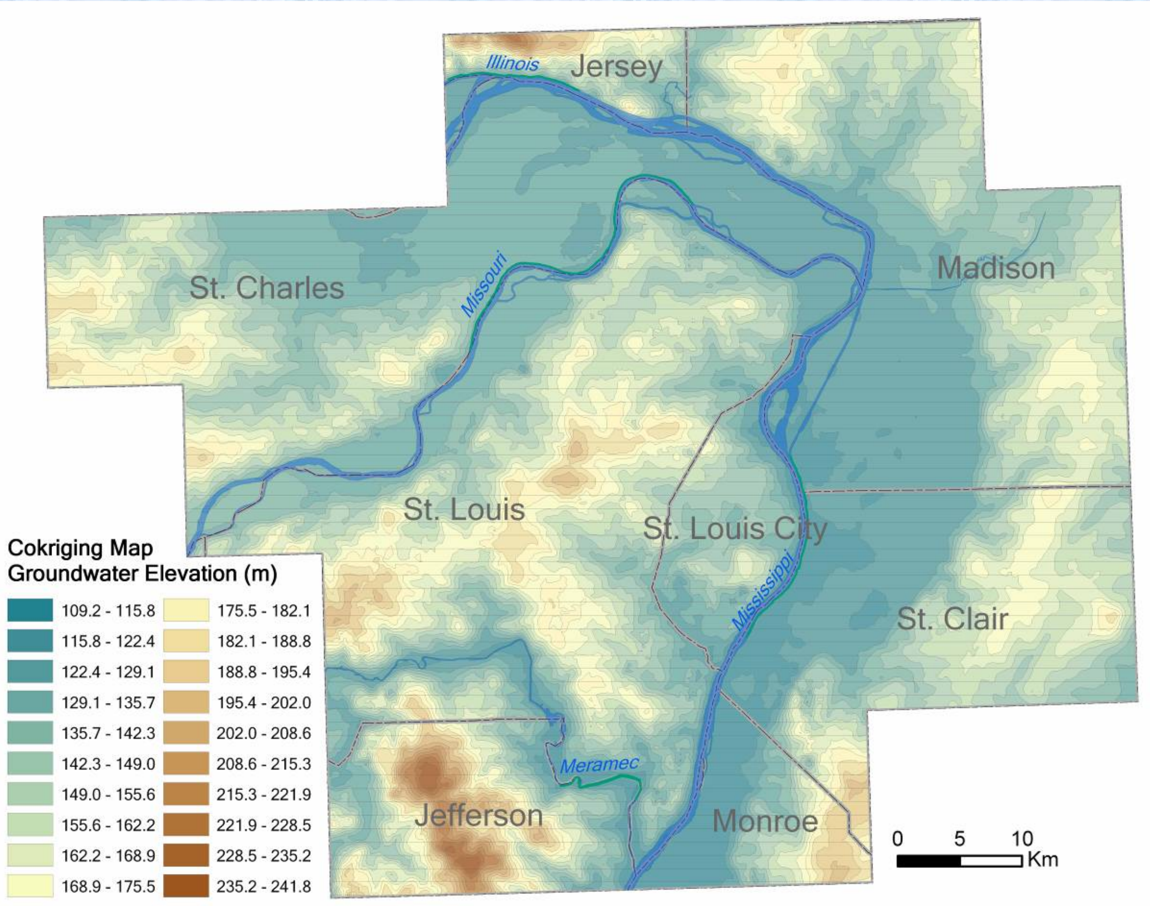
Primary variables:

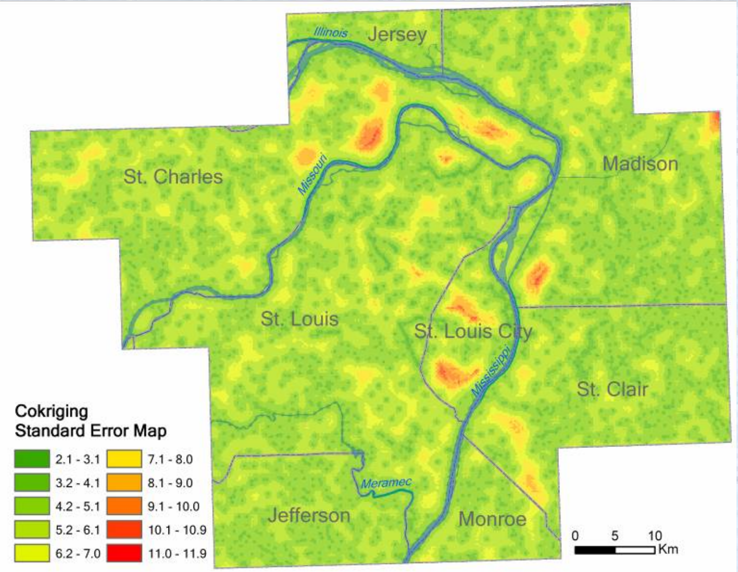
- 1,052 well logs
- 2,569 artificial data points along drainage.

Secondary variable:

- Ground elevation (500m × 500m grids) extracted from USGS DEMs

2) Cokriging Map of Groundwater Table





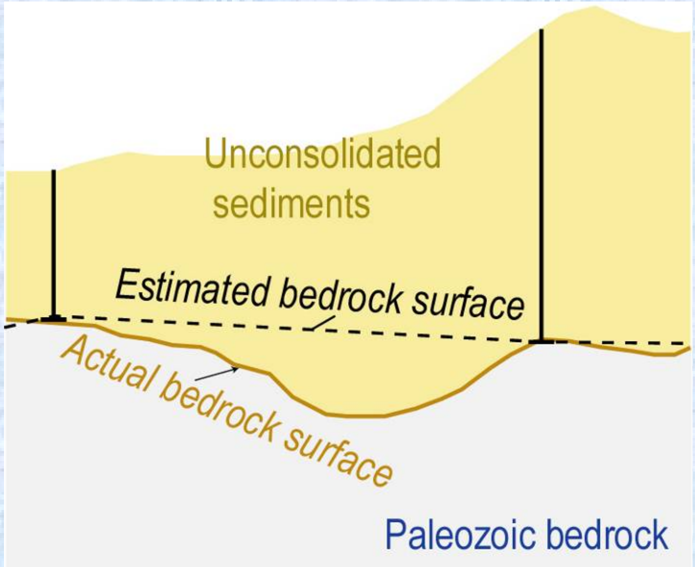
- Raster data model

Standard Error Map Using Cokriging

Problems with interpolating the Bedrock Surface

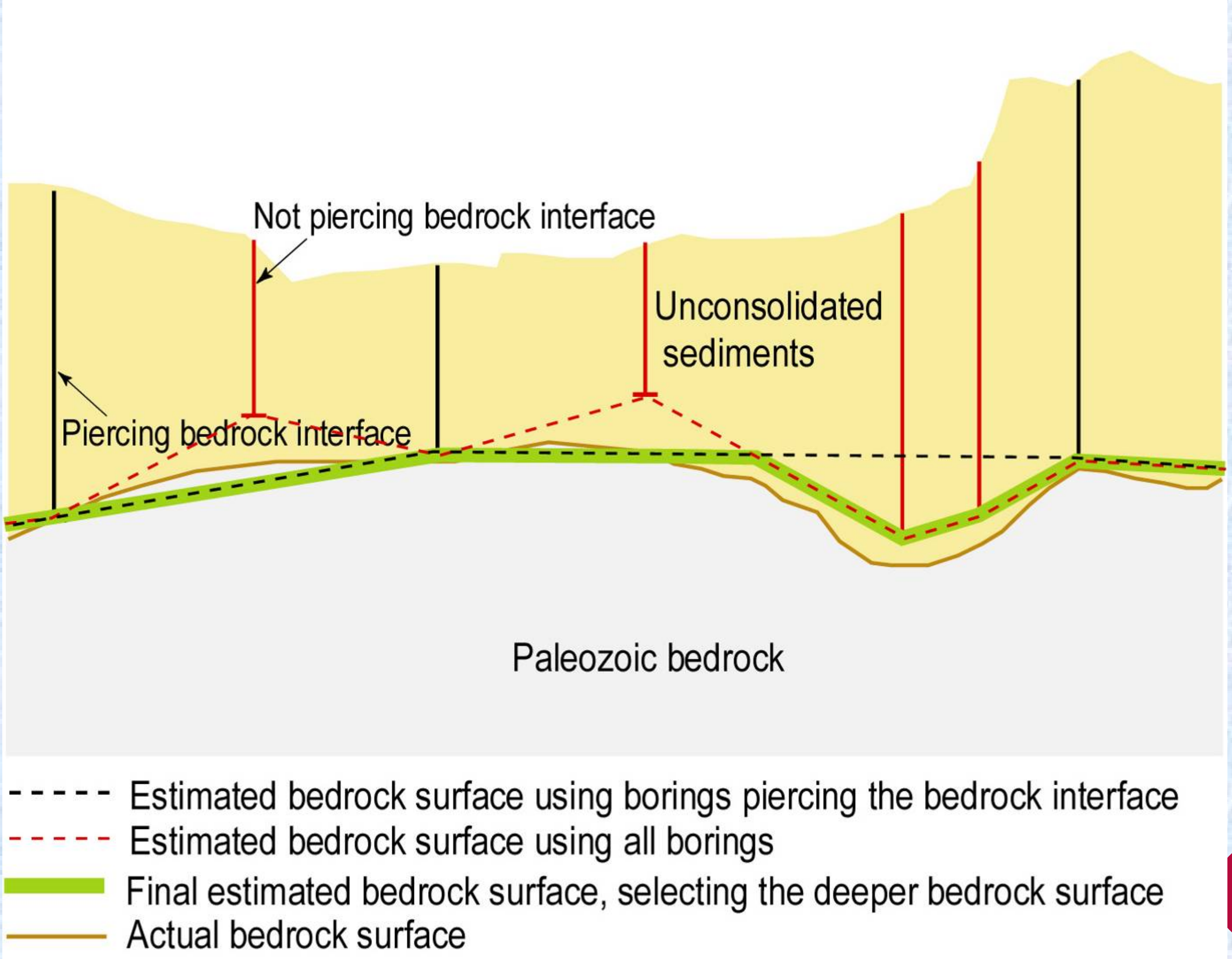
In undulating terrain, the bedrock surface often presents a complex feature, shaped by numerous erosional and deformational events

- **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**



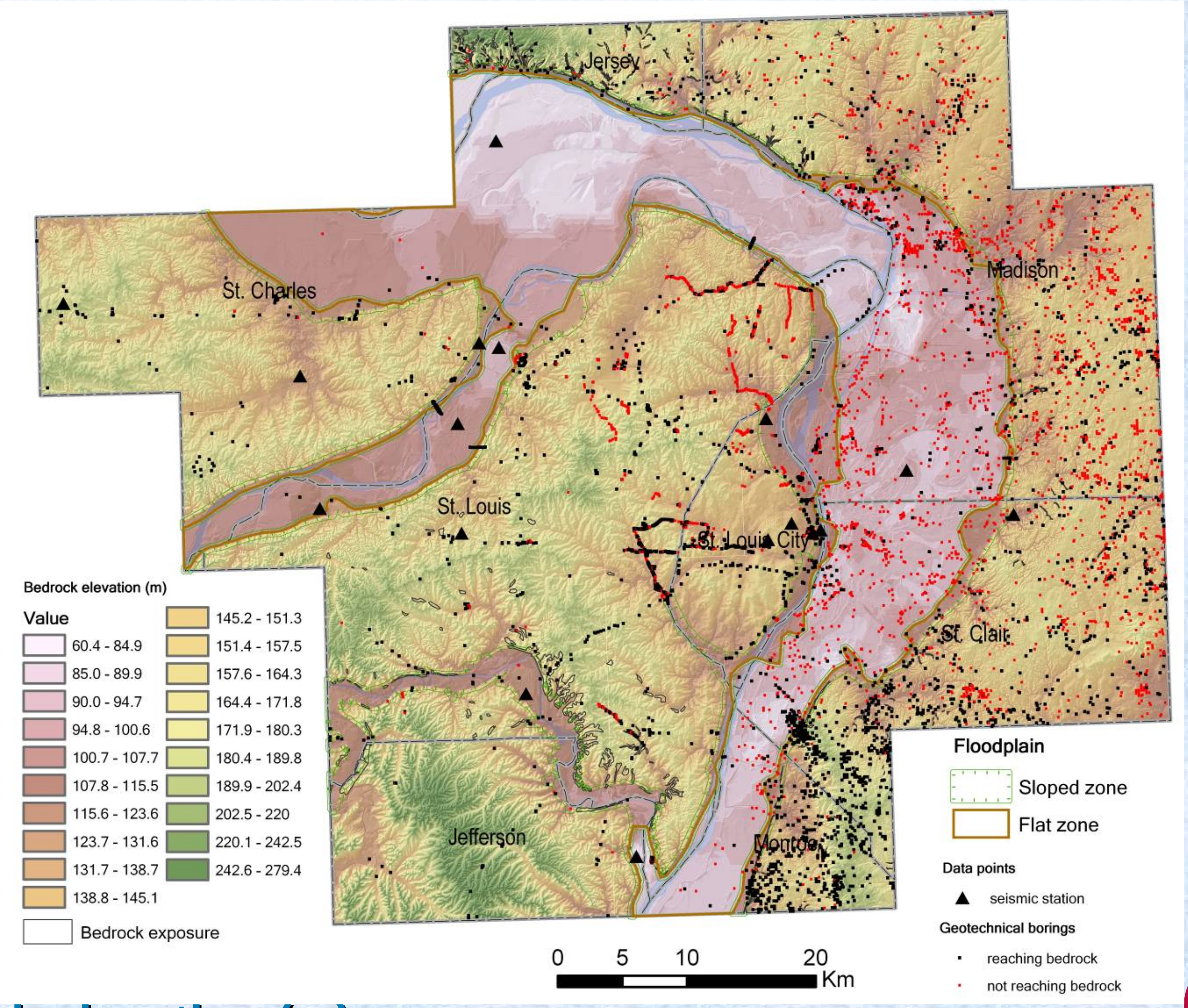
Procedure for Interpolating Depth-to-Bedrock

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

Preliminary Assessment of Soil Liquefaction Potential

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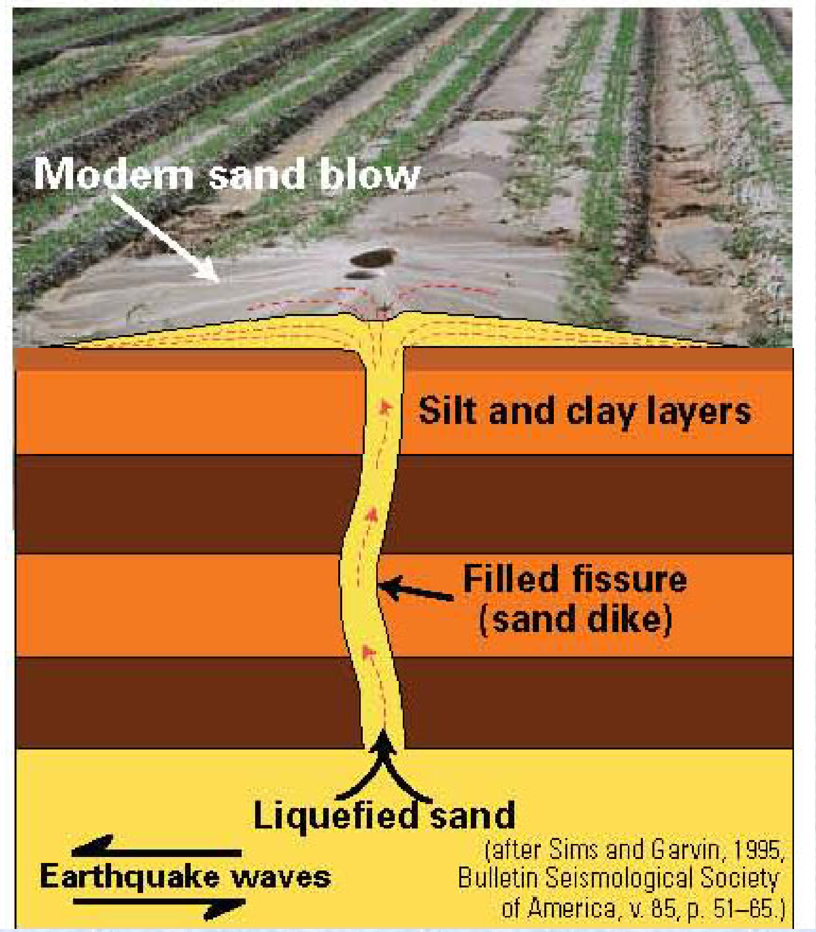
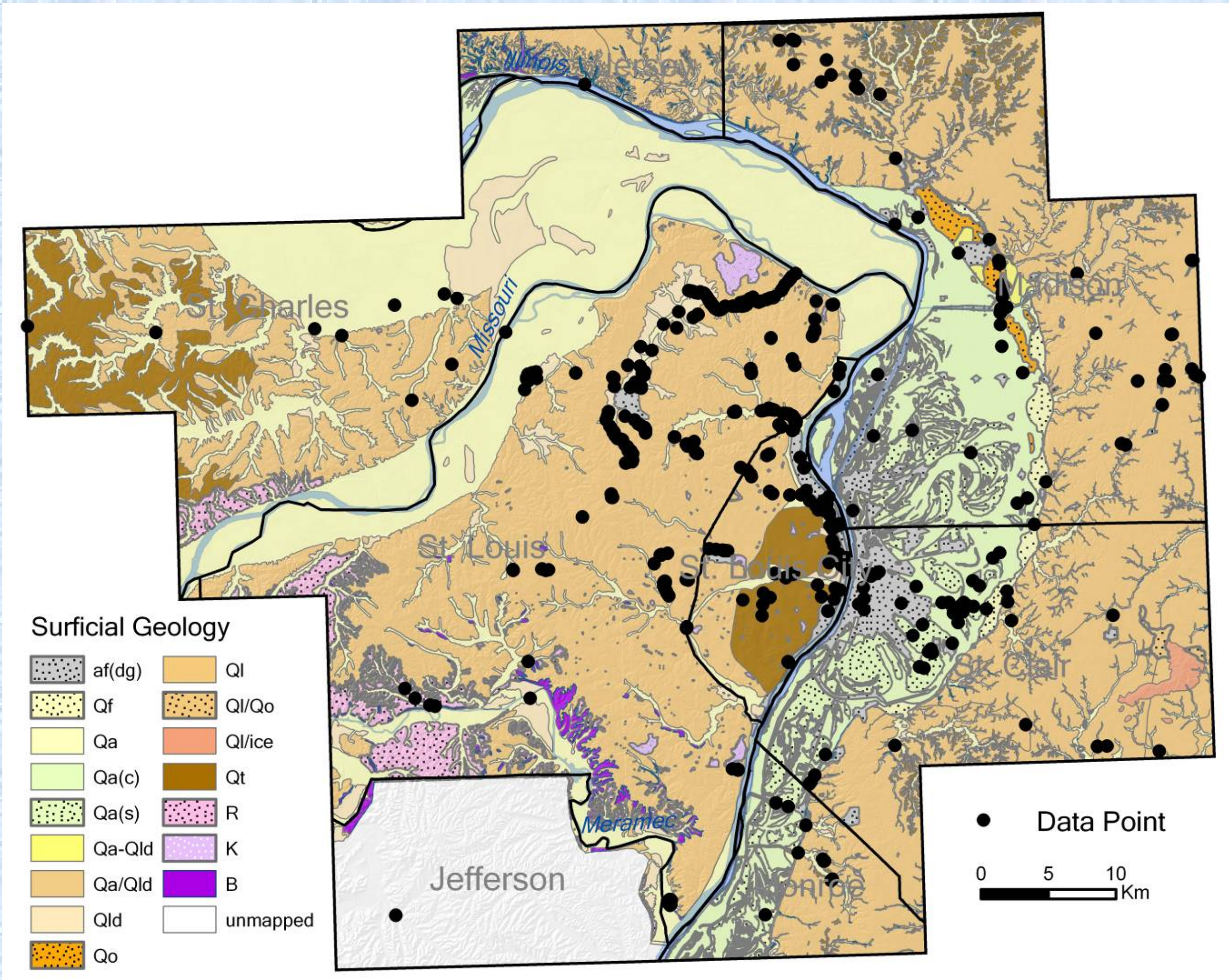
Liquefaction is a soil failure mechanism that occurs when saturated cohesionless soil looses shear strength. This occurs when the soil pore pressure exceeds the effective confining stress.

It often occurs in loose unconsolidated sands during earthquake-induced ground shaking, and **behaves like a *fluid***.

When the water pressure increases and sand is liquefied, *a **slurry of sand/water** is forced to the ground surface.*



Locations of 564 Borings used to calculate the Liquefaction Potential Index, or LPI



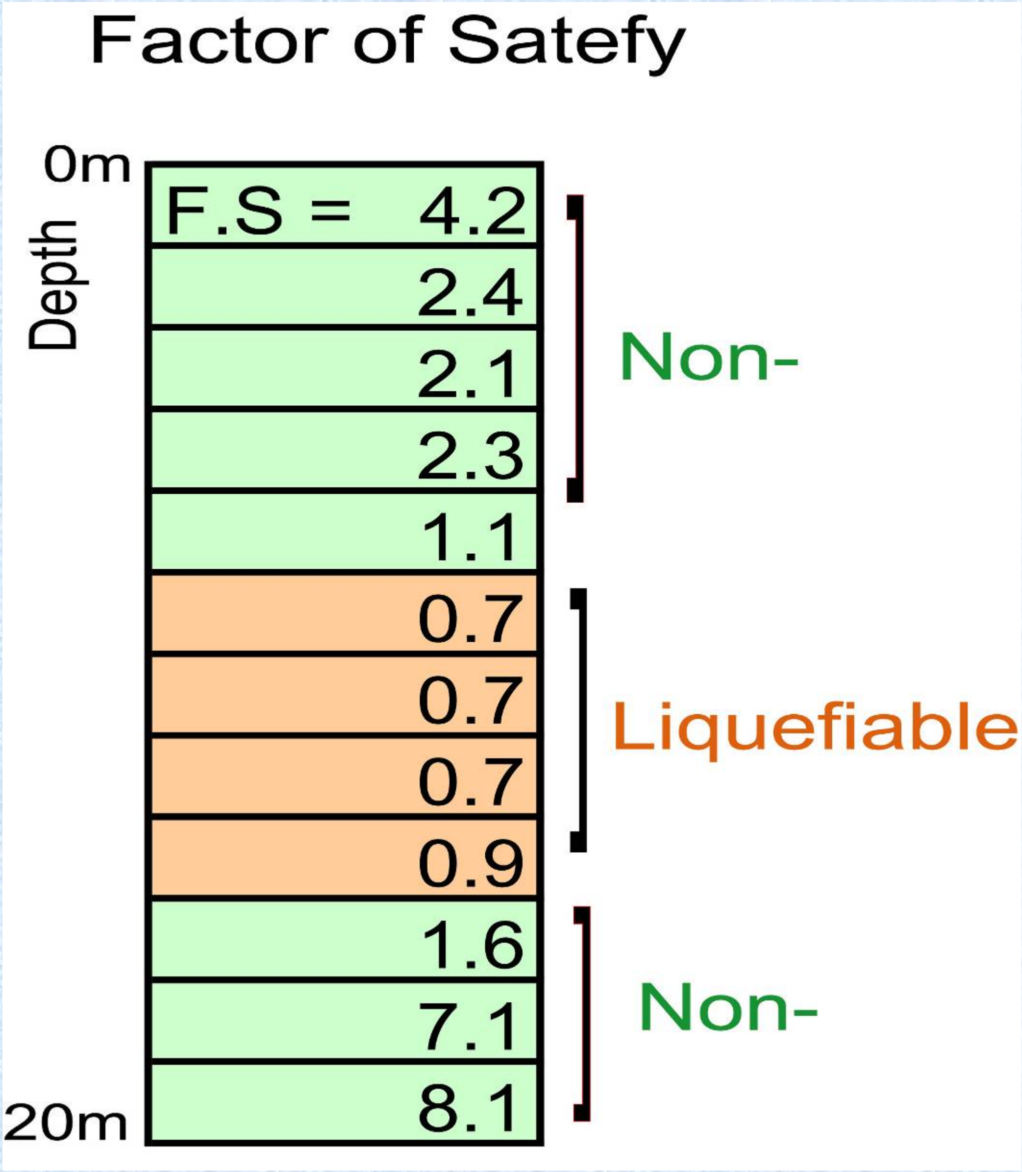
- **Data Sources** (Boring information):
  - **MoDNR-DGLS, ISGS**

Historical Liquefaction Severity Assessed from LPI (Iwasaki, 1982)

LPI	Severity of Liquefaction
0	None
$0 < LPI \leq 5$	Little to none
$5 < LPI \leq 15$	Moderate
$15 < LPI \leq 100$	Severe

- **The higher LPI value, the more severe liquefaction damage.**

Advantage of LPI over FS

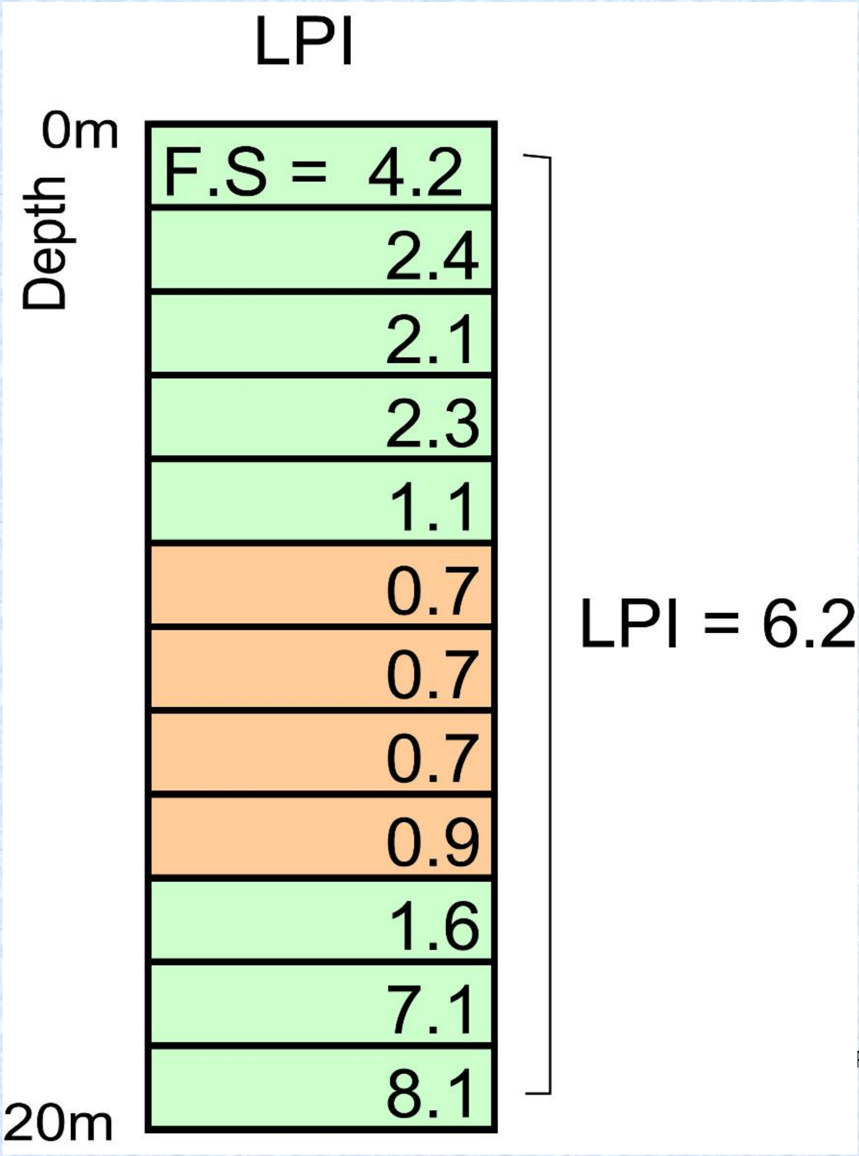


Where the mixture of a liquefiable and non-liquefiable soil layer exists at a single boring,

Will liquefaction occur?

If so, how severe is the liquefaction?

Advantages of LPI over FS



LPI = 6.2 in this soil column;

therefore,liquefaction is likely to occur

Liquefaction severity will be "MODERATE", based on historical liquefaction evidences (Iwasaki et al., 1982)

Calculation LPI and Earthquake Scenario

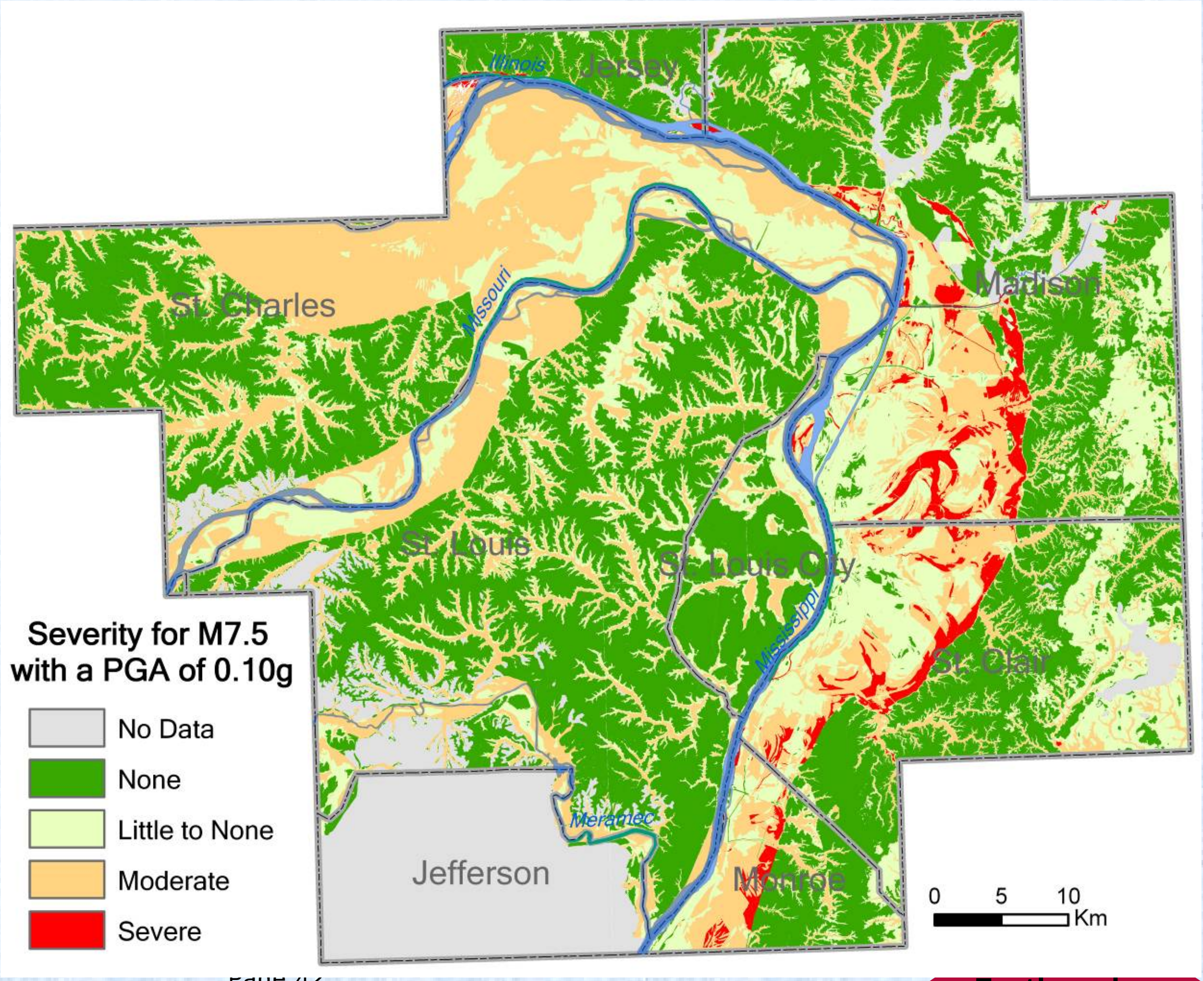
Liquefaction potential in the upper Mississippi Embayment may not be a significant issue at Magnitudes < 6.4 (Obermeier, 1989; Tuttle and Schweig, 1995)

LPI values (564 data points) were calculated for a M7.5 quake with a PGA of 0.10g to 0.30g (Toro and Silva, 2001), emanating from the ***New Madrid Seismic Zone***

Liquefaction Potential Map (inferred from LPI) for M7.5 with 0.10 PGA

Severe Liquefaction Potential Area (LPI>15):

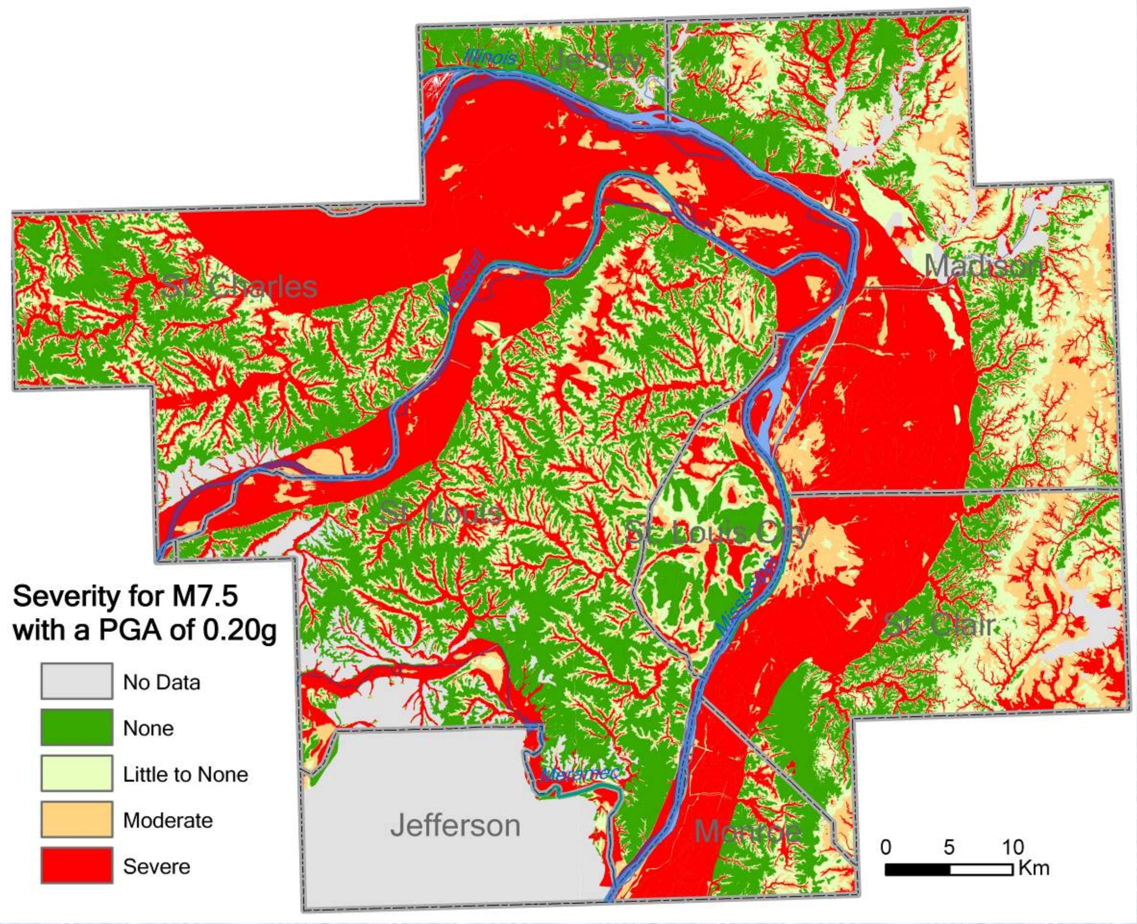
- **Alluvial fans in part (where, DTW<0.5m) in Illinois**
- **Near confluence of Mississippi-Illinois rivers**



- Grey areas have insufficient # of borings

Liquefaction Potential Map (inferred from LPI) for M7.5 with 0.20 PGA

- **Severe Liquefaction Potential Area (LPI>15):**
  - **Alluvial fan in part (DTW<4.7m) in Illinois**
  - **Alluvium in part (DTW<4.4m) along major rivers and streams**
  - **Clayey alluvium (DTW<4.6m) and sandy alluvium (DTW<5.1m) in ox bow and adjacent alluvial fan**



Physical Factors Affecting Seismic Site Response

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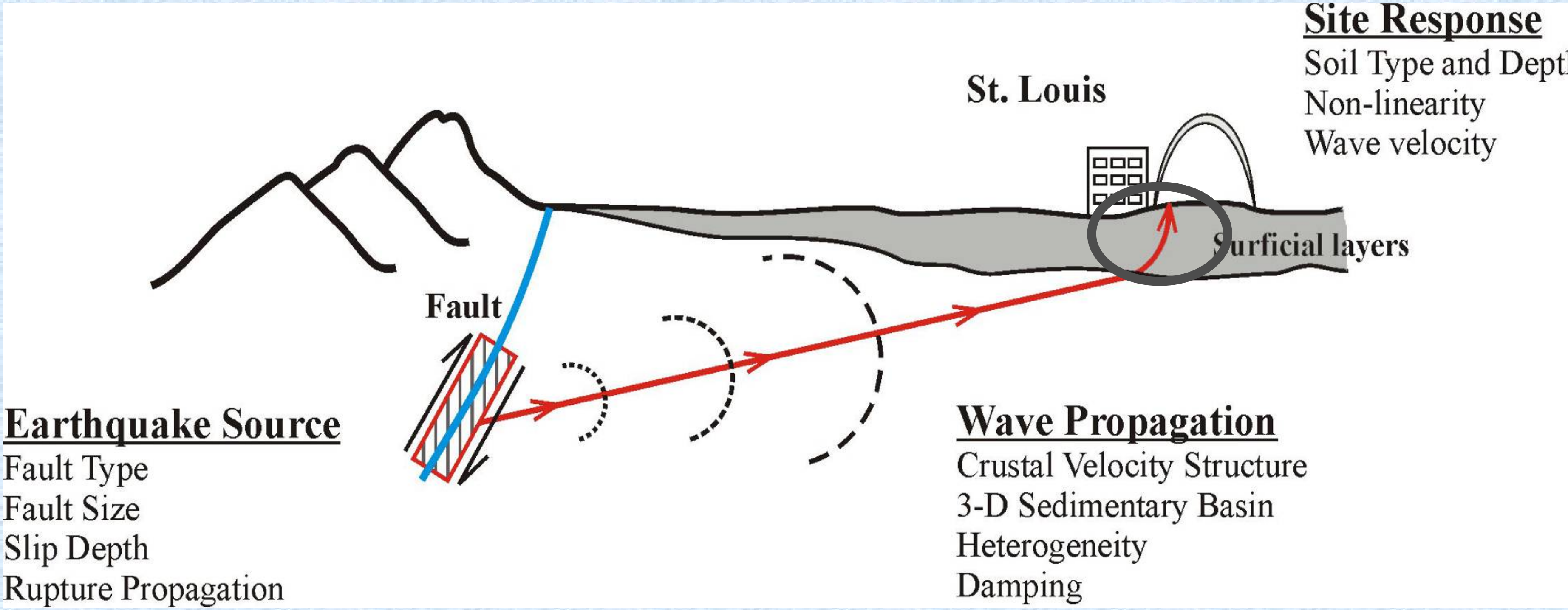
What is Site Response? How the soil under the site affects the intensity of ground shaking.



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

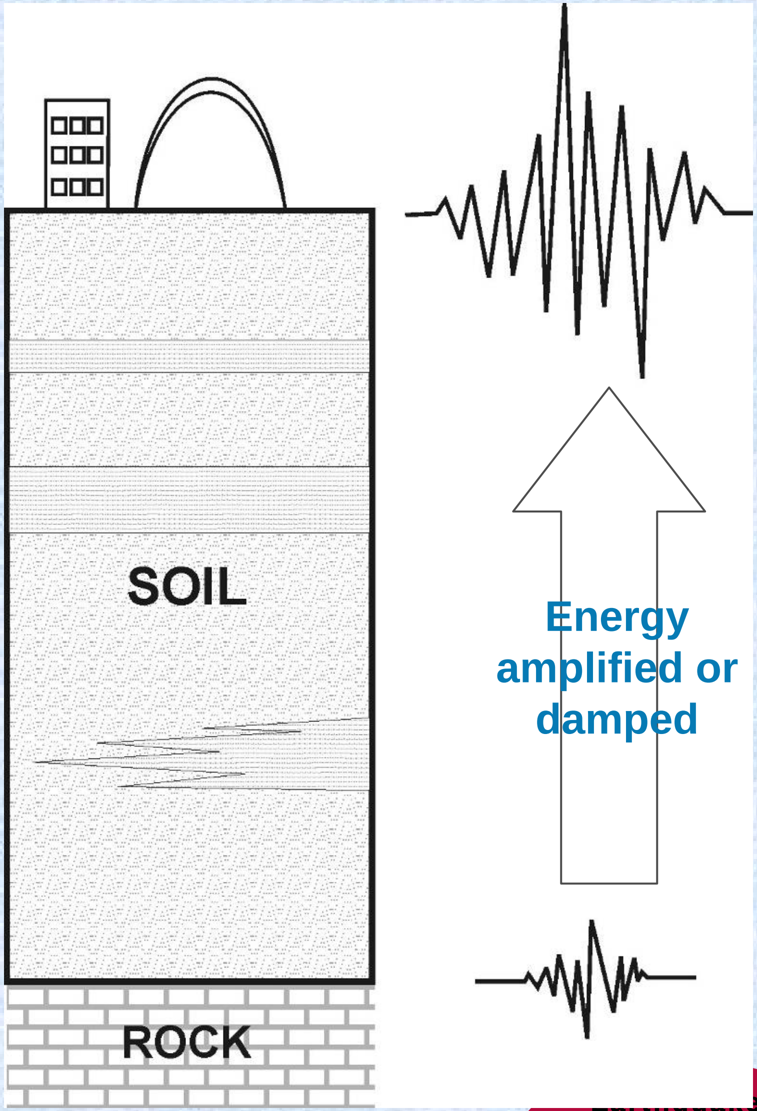
Estimating surface accelerations

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



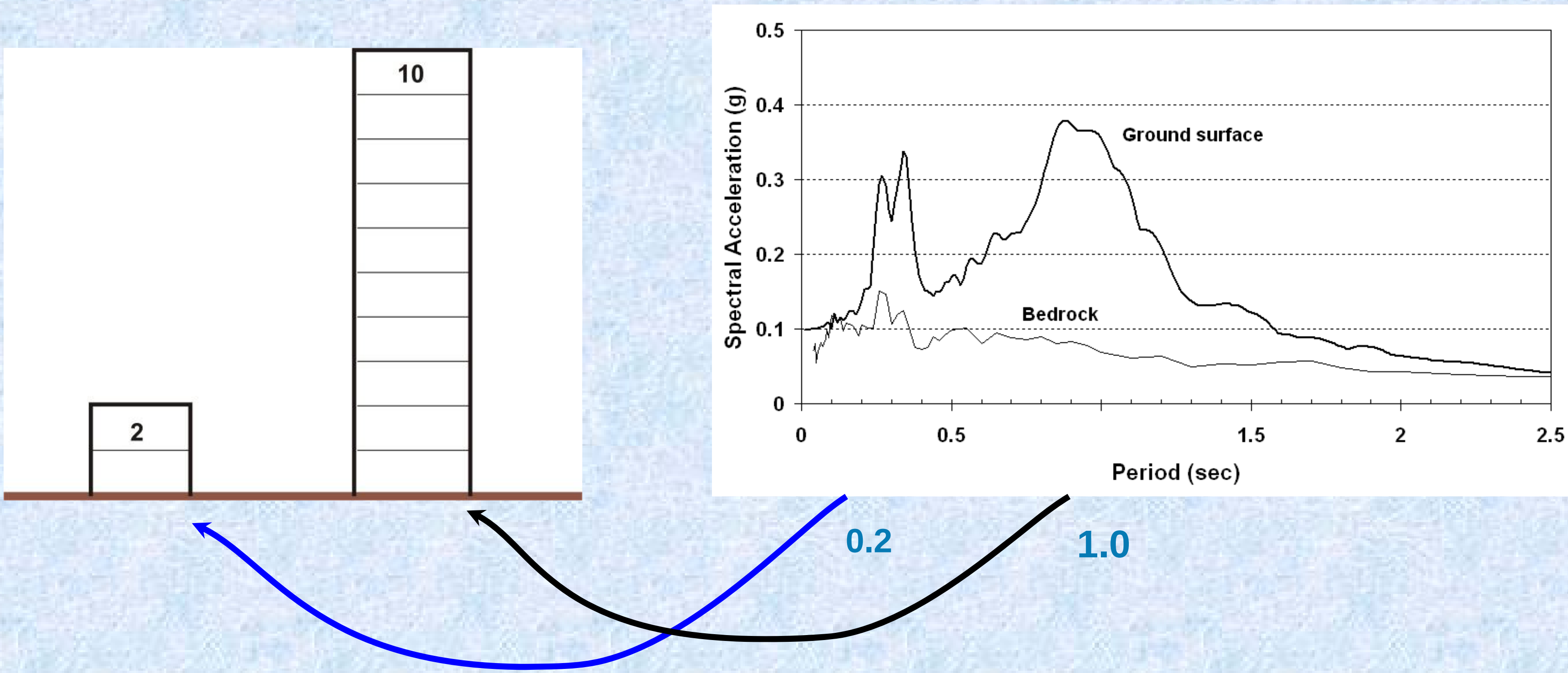
Ground Motion Parameters

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

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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

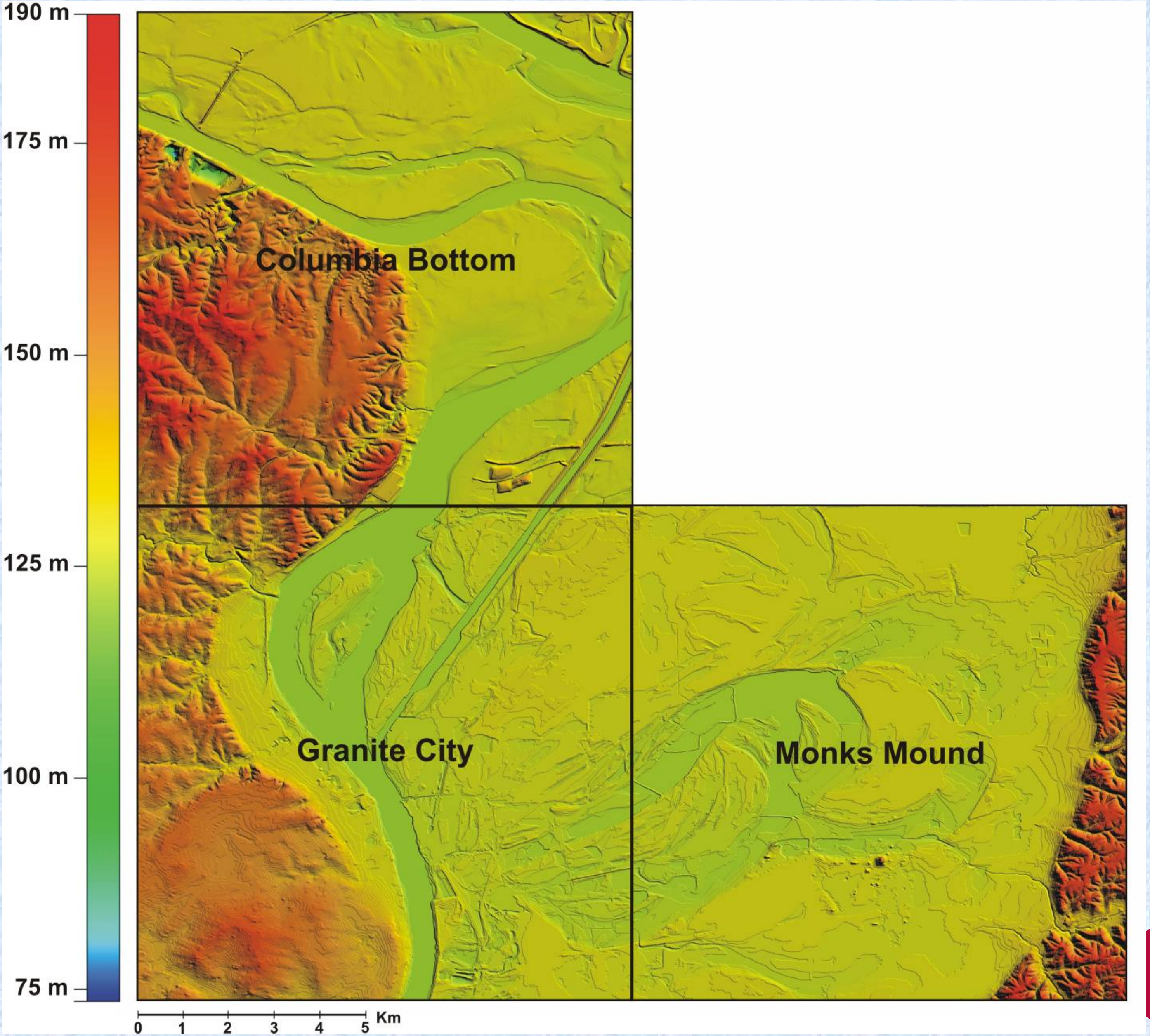
3) Characterize the thickness and shear wave velocity of the bedrock underlying the surficial materials

4) Characterize the properties of the surficial materials (~soil cap)

Physical soil properties

Dynamic soil properties (shear modulus and damping, shear wave velocity)

Digital Elevation Model



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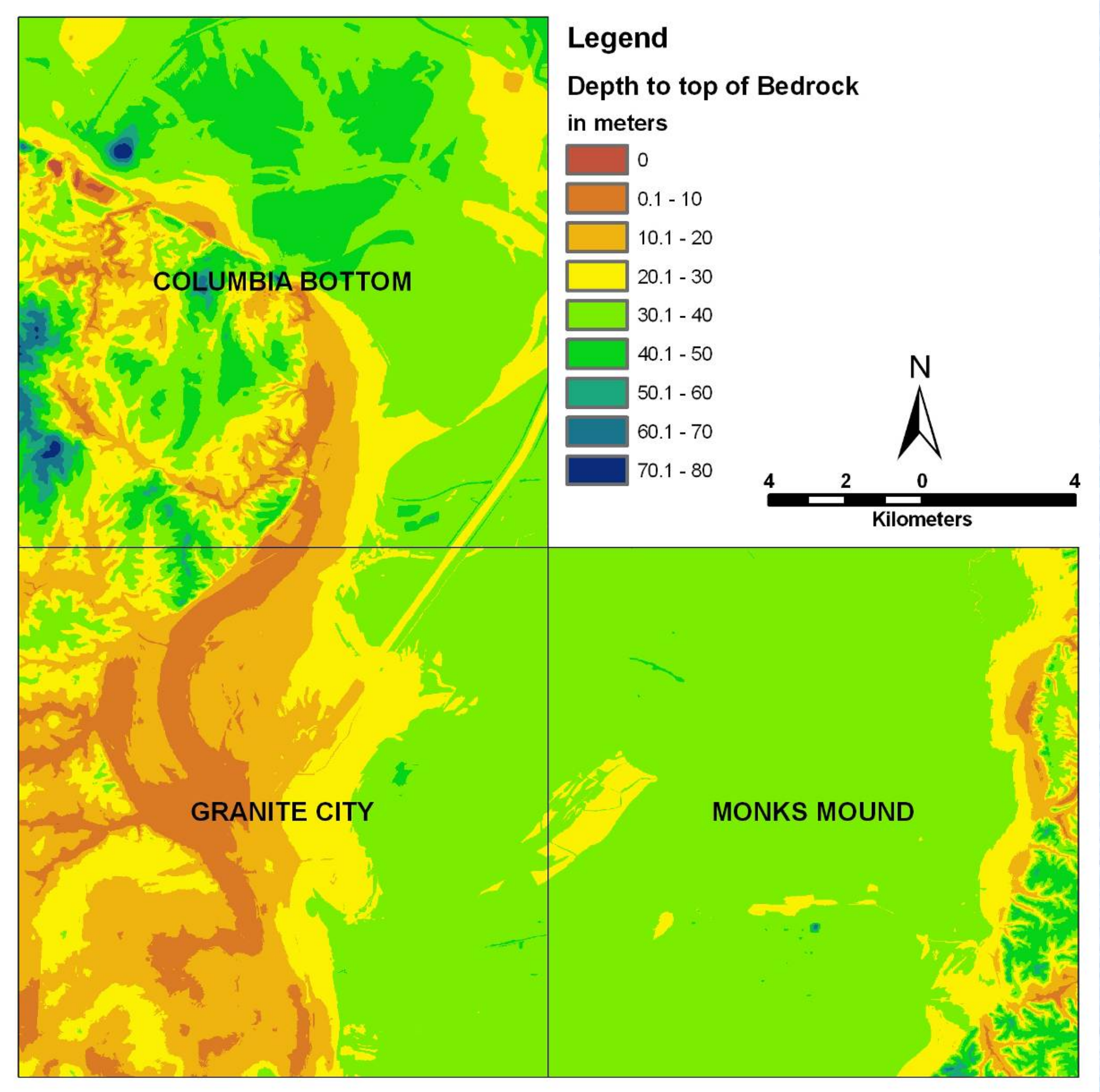
Depth to Bedrock (Surficial Geology Thickness Map)

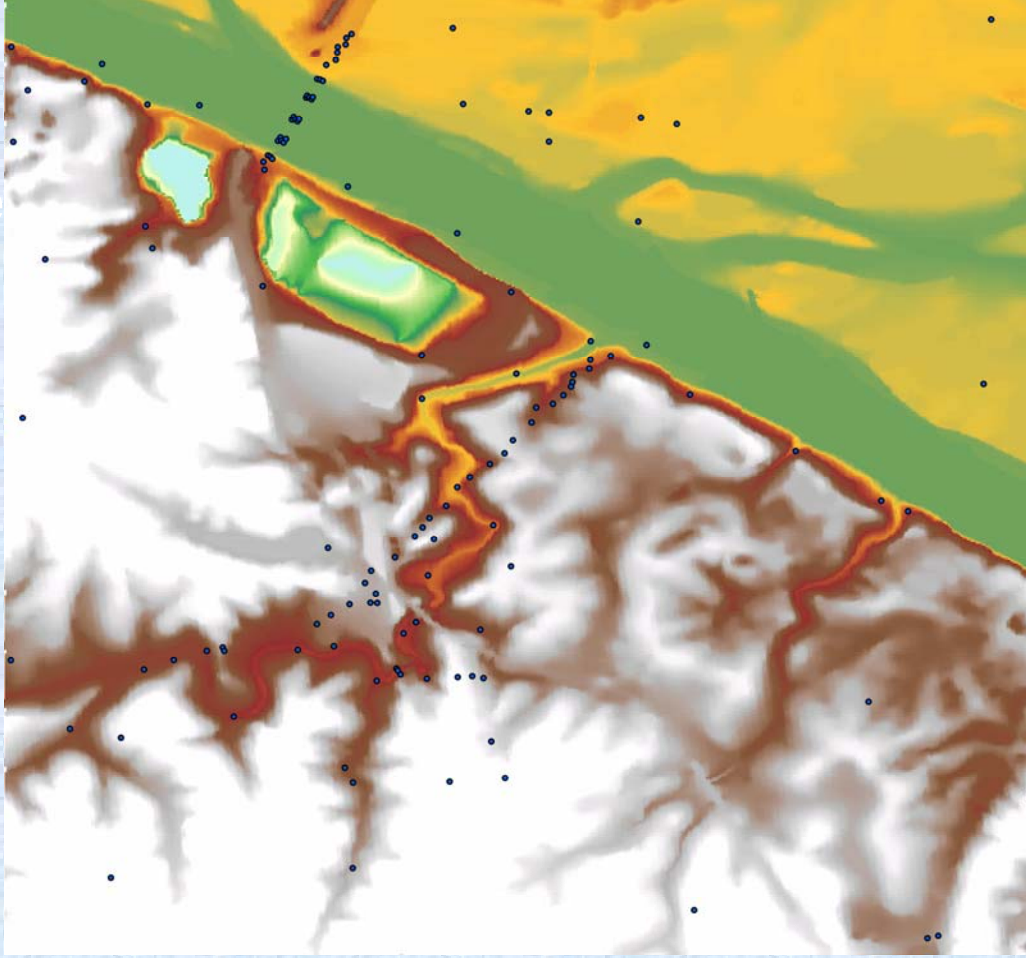


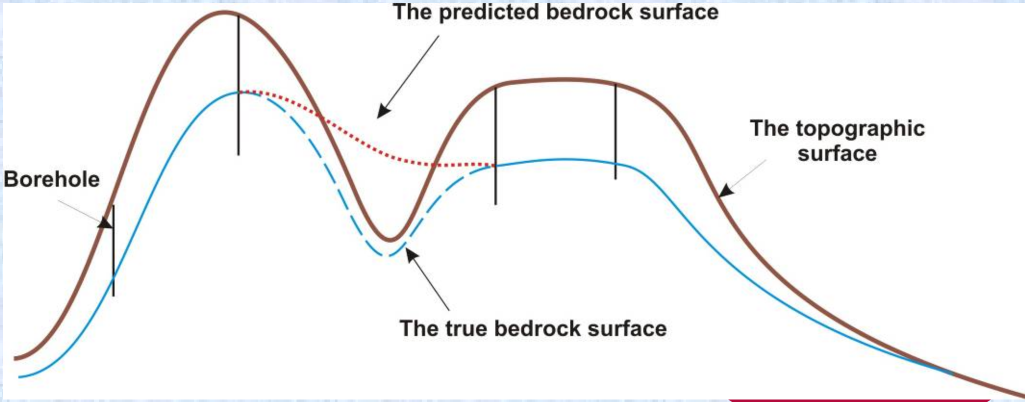
Drawbacks

When the bedrock surface is uniform there is little uncertainty in the calculations. However, large variations in the data within small distances cause problems in the predictions.

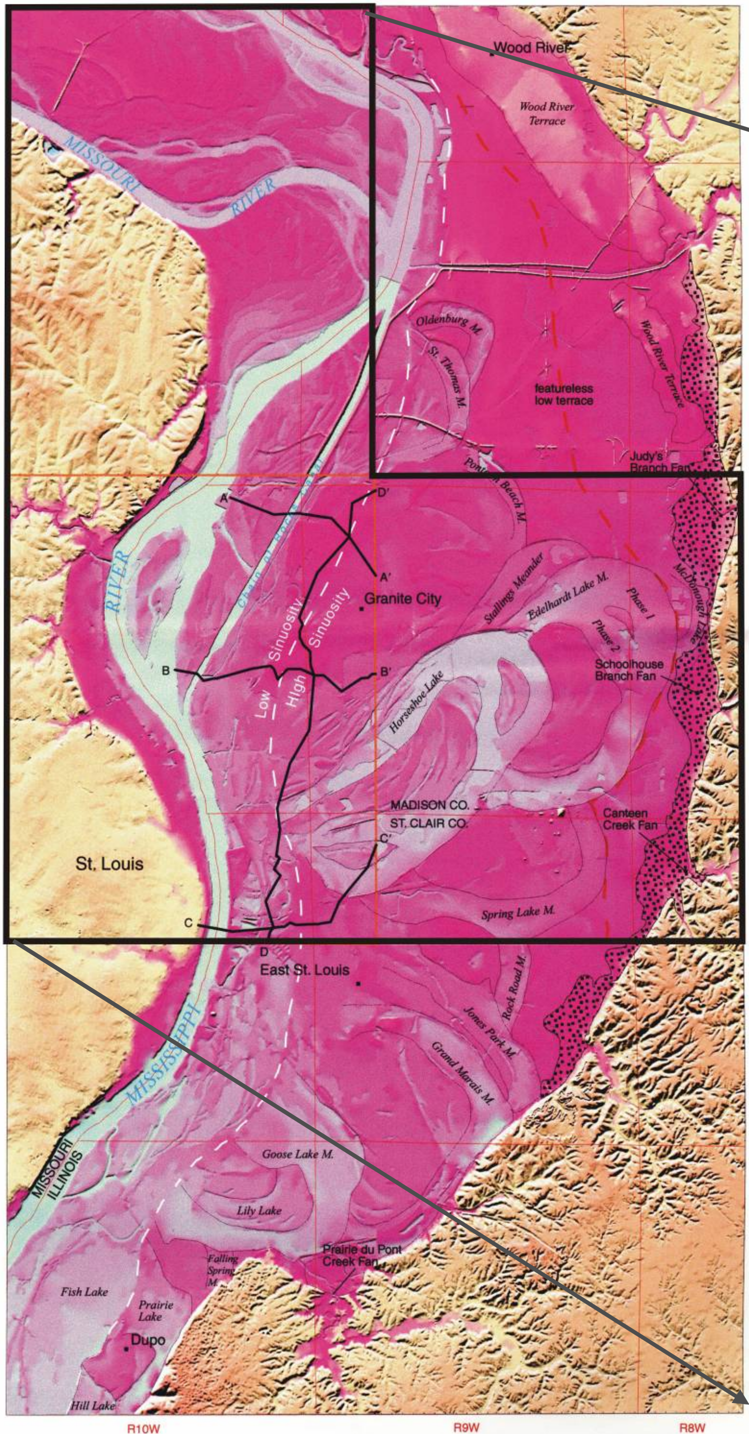
The loess deposits mantling uplands tend to thicken towards hilltops and thin towards valleys, because of erosion.

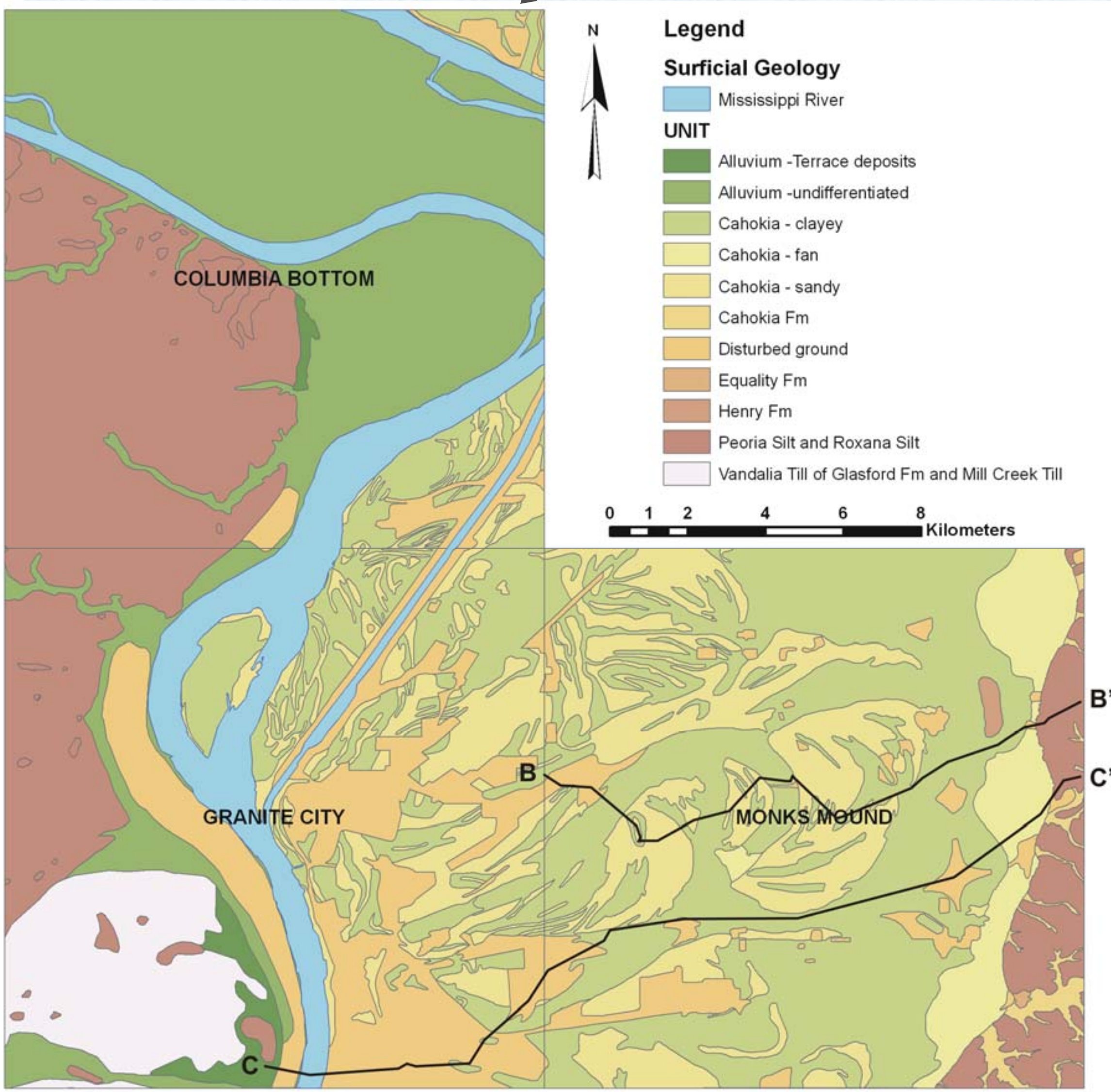
When thickness data is missing in these valleys, kriging techniques can be unreliable, as shown at lower right.





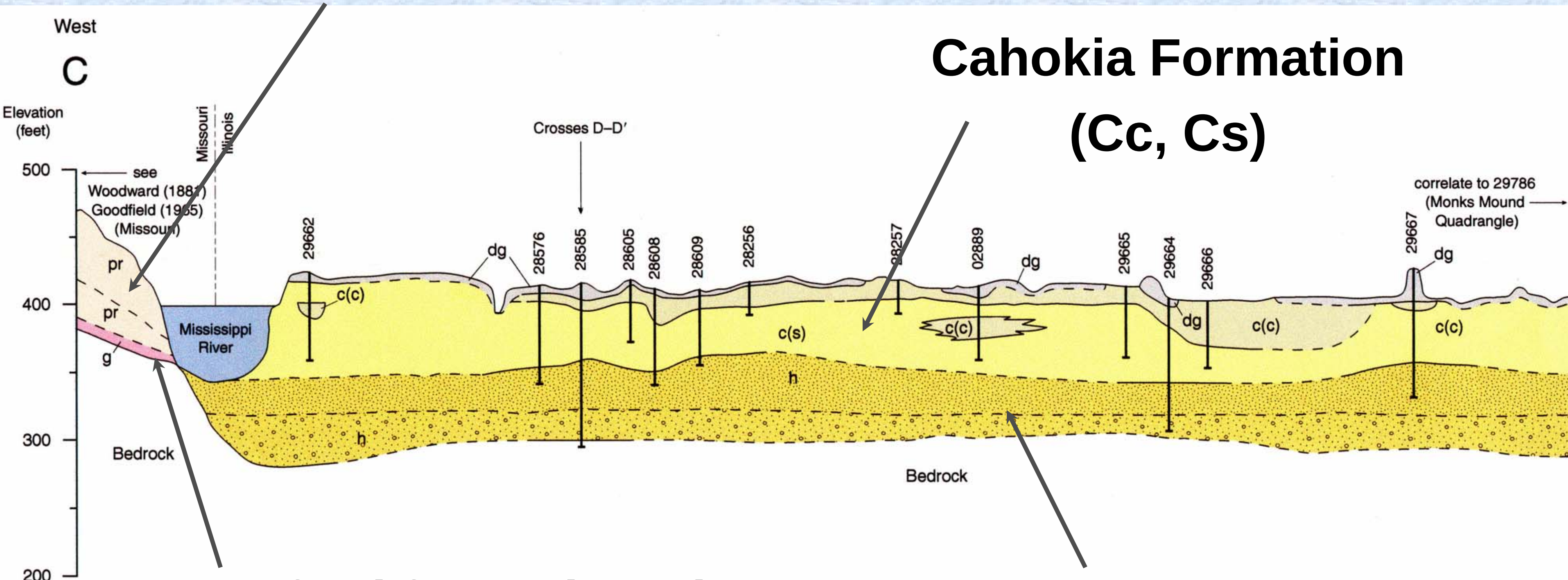
Surficial Geology of St. Louis study area





Typical Cross section thru Mississippi flood plain

Peoria and Roxana Silt -loess

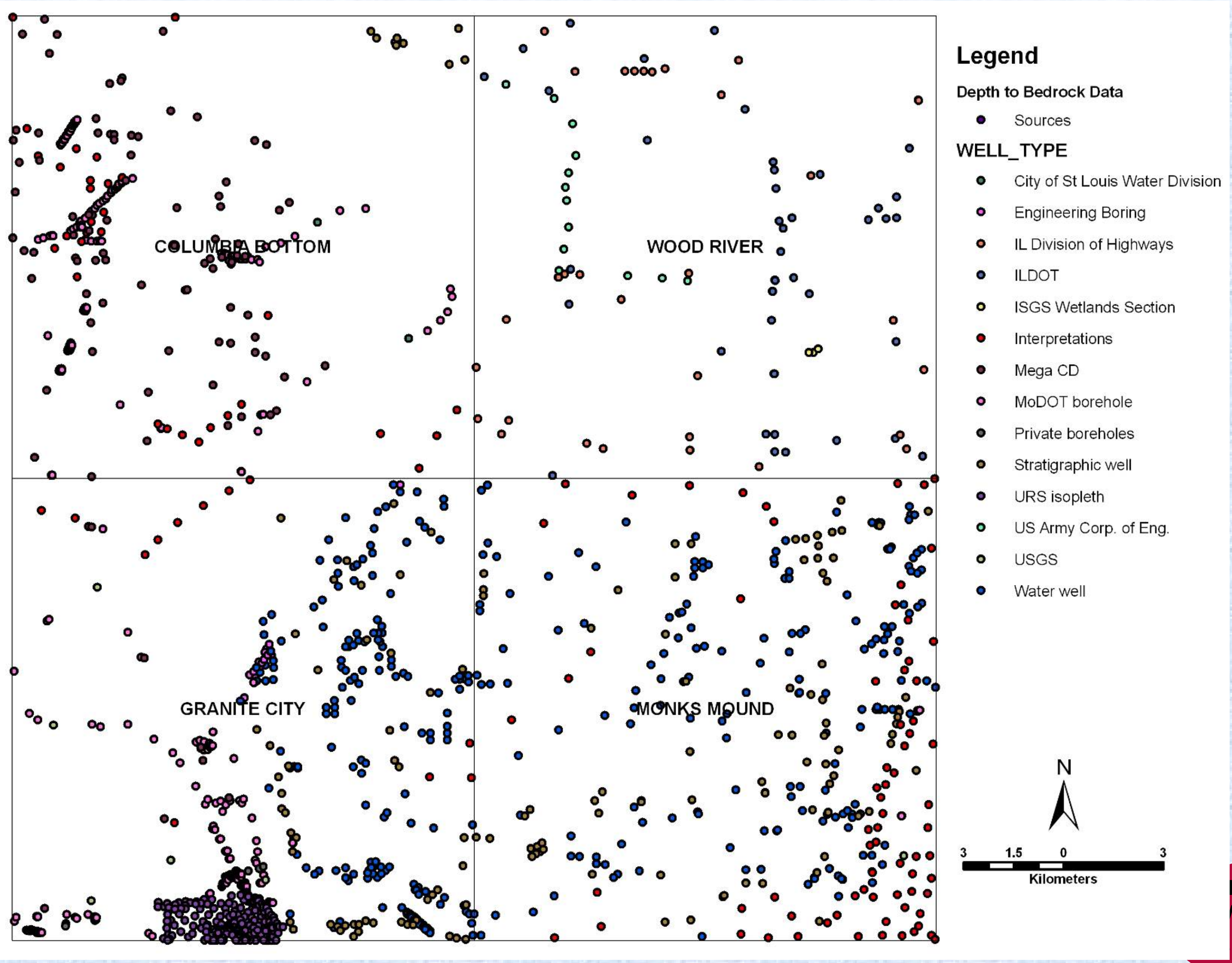


Cahokia Formation (Cc, Cs)

Glasford formation -till

Henry Formation (h)

Location of Boreholes



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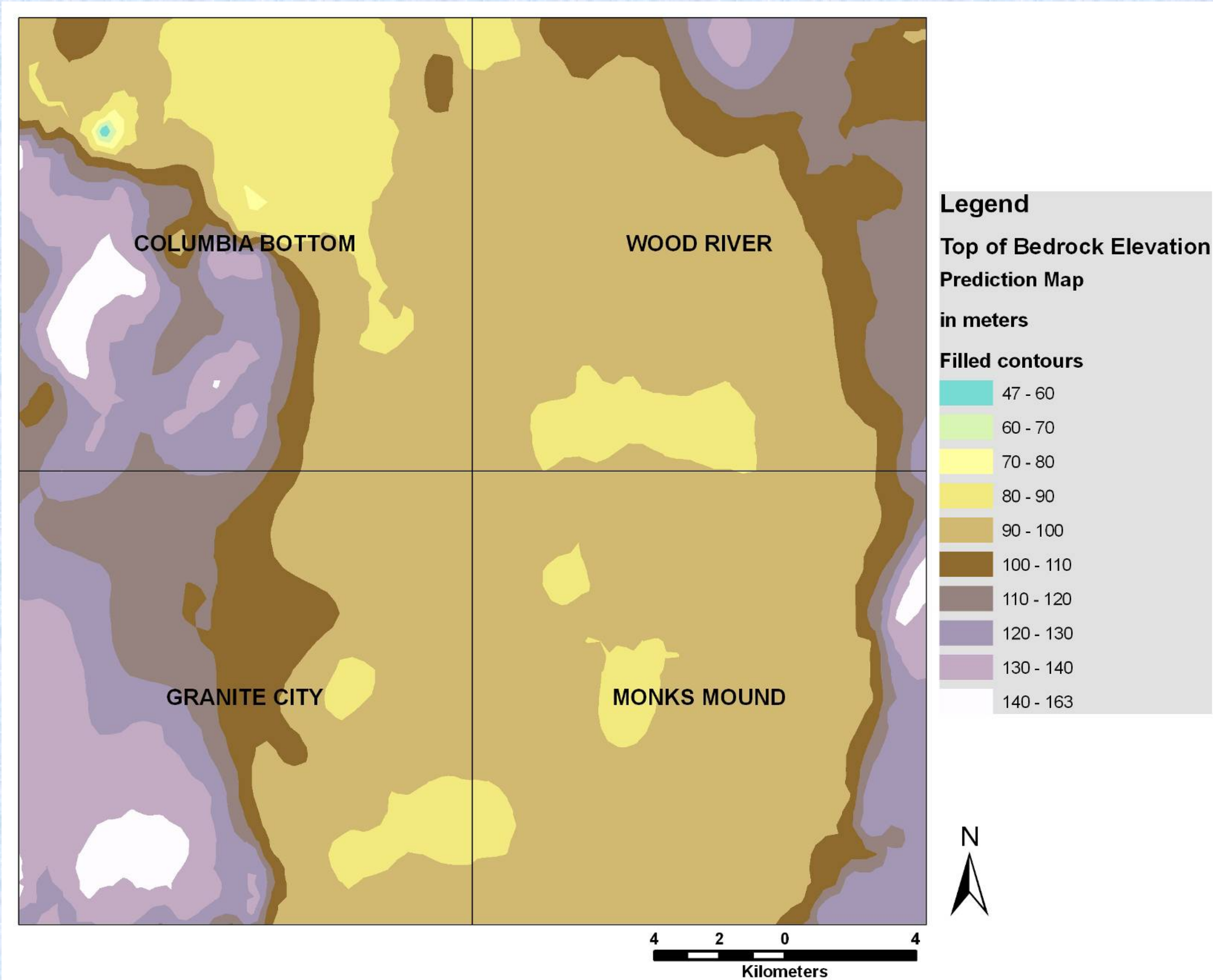
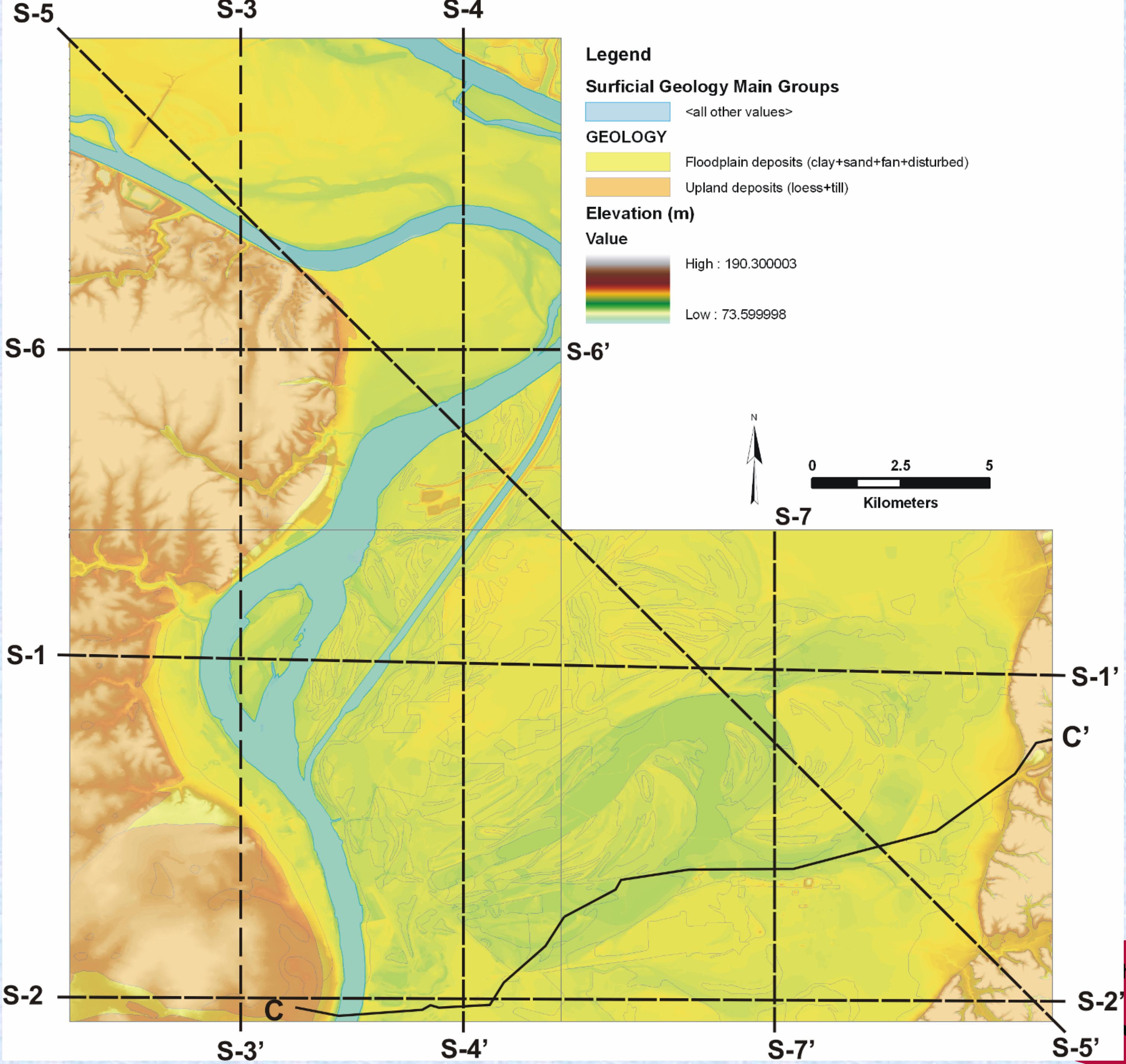
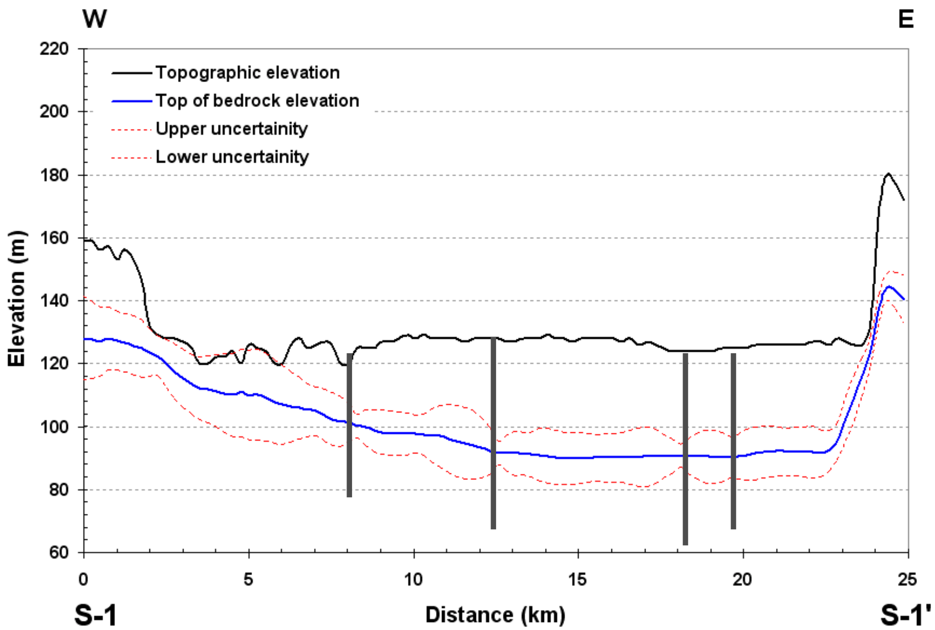
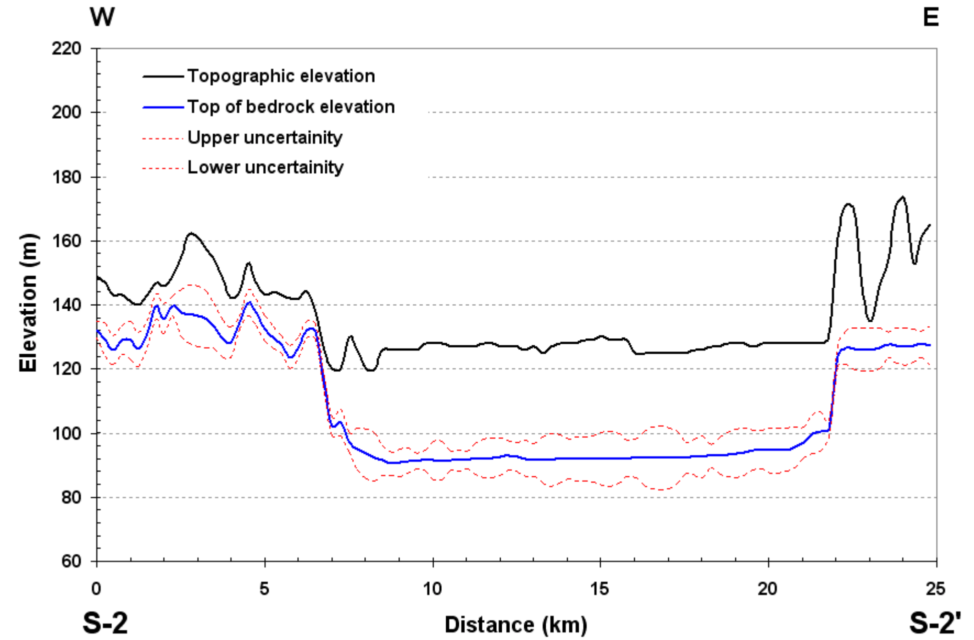
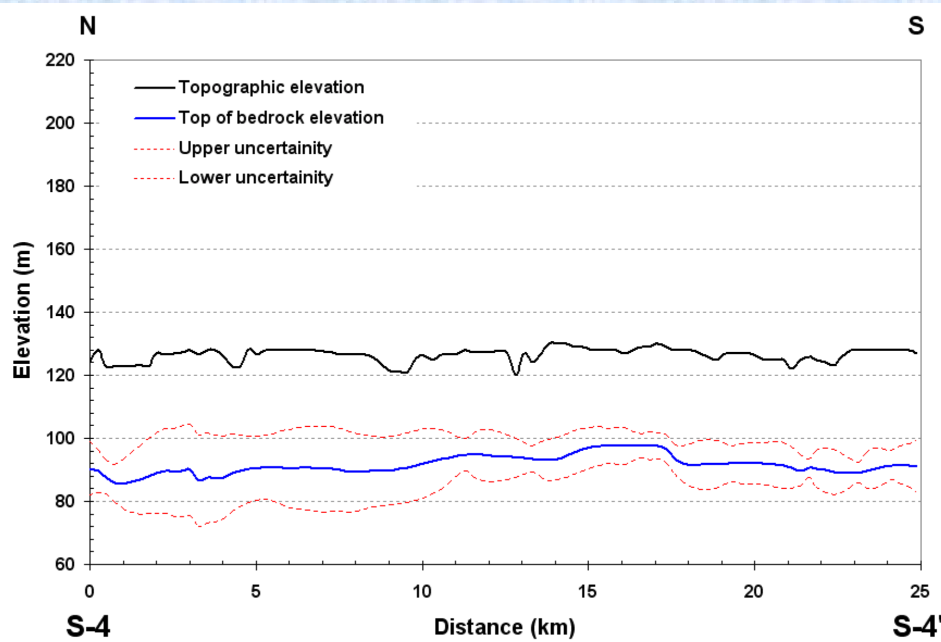
Estimation of Top of Bedrock Elevations

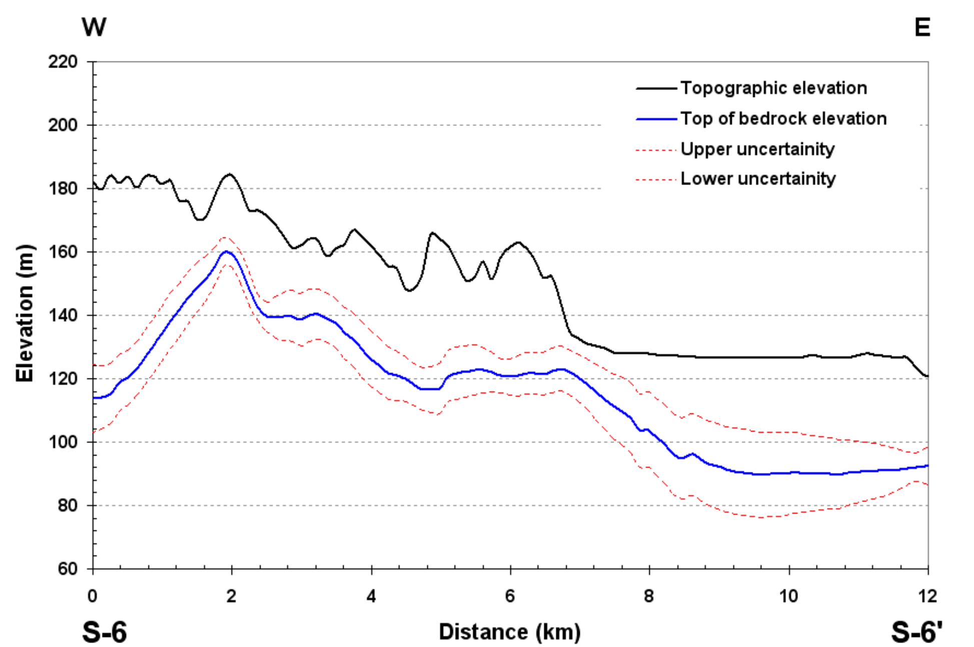



S-5
S-3
S-4
Legend
Surficial Geology Main Groups
<all other values>
GEOLOGY
Floodplain deposits (clay+sand+fan+disturbed)
Upland deposits (loess+till)
Elevation (m)
Value
High : 190.300003
Low : 73.599998
S-6
S-6'
N
0
2.5
5
Kilometers
S-7
S-1
S-1'
C'
S-2
C
S-2'
S-3'
S-4'
S-7'
S-5'


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'

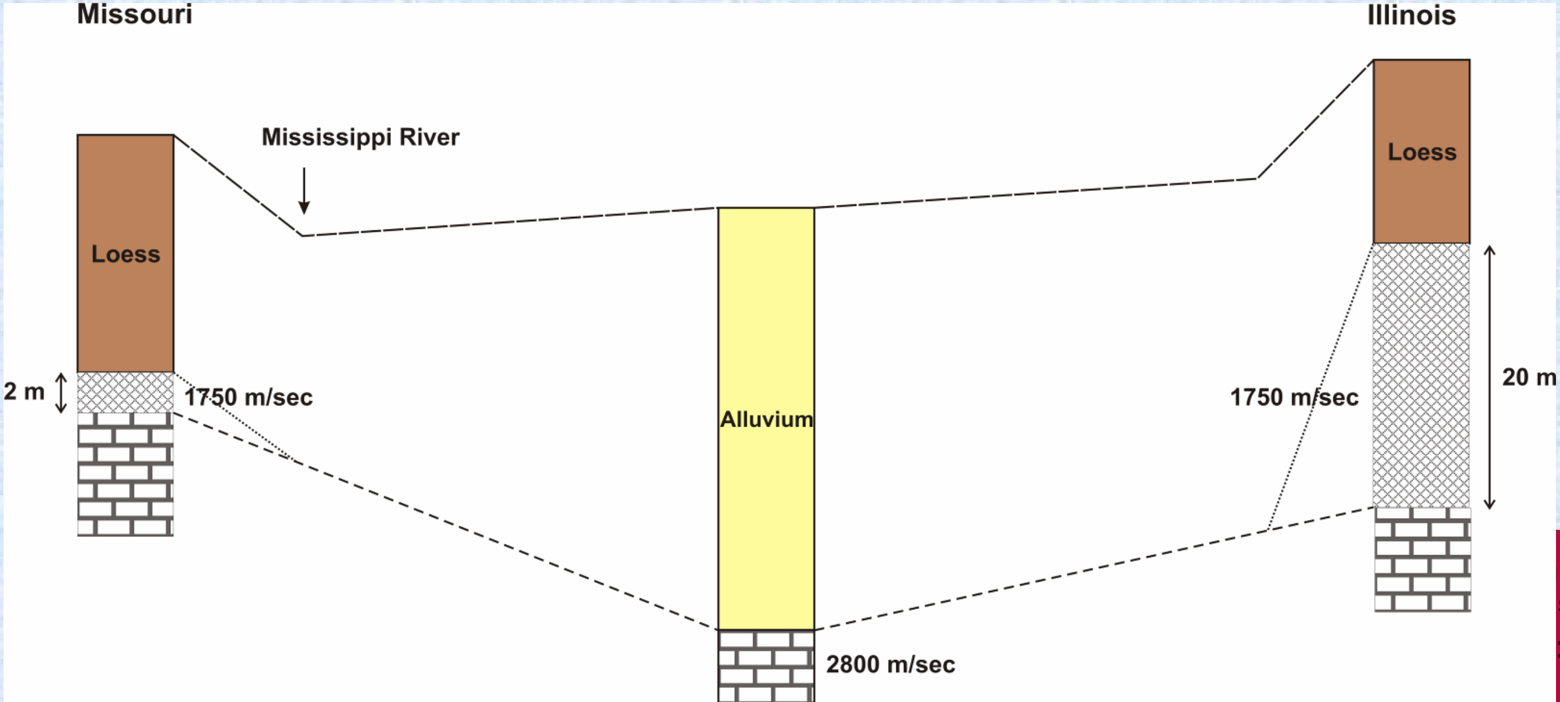

W
E
Topographic elevation
Top of bedrock elevation
Upper uncertainity
Lower uncertainity
Elevation (m)
Distance (km)
S-6
S-6'

Bedrock properties

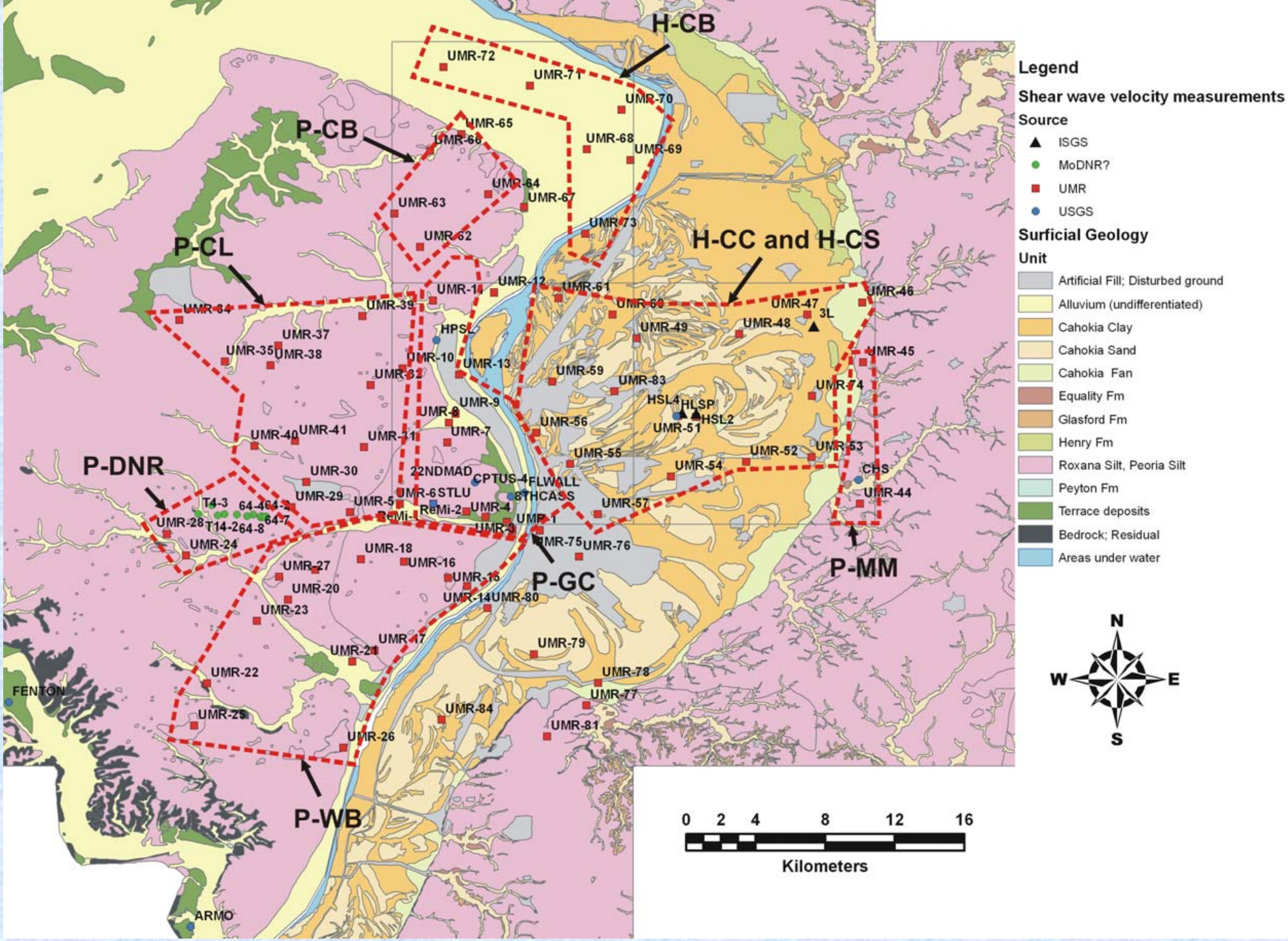
We used 1750 m/sec +/- 250 m/sec for the weathered bedrock shear-wave velocity, as suggested by Prof. Robert Herrmann at St. Louis University.

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.



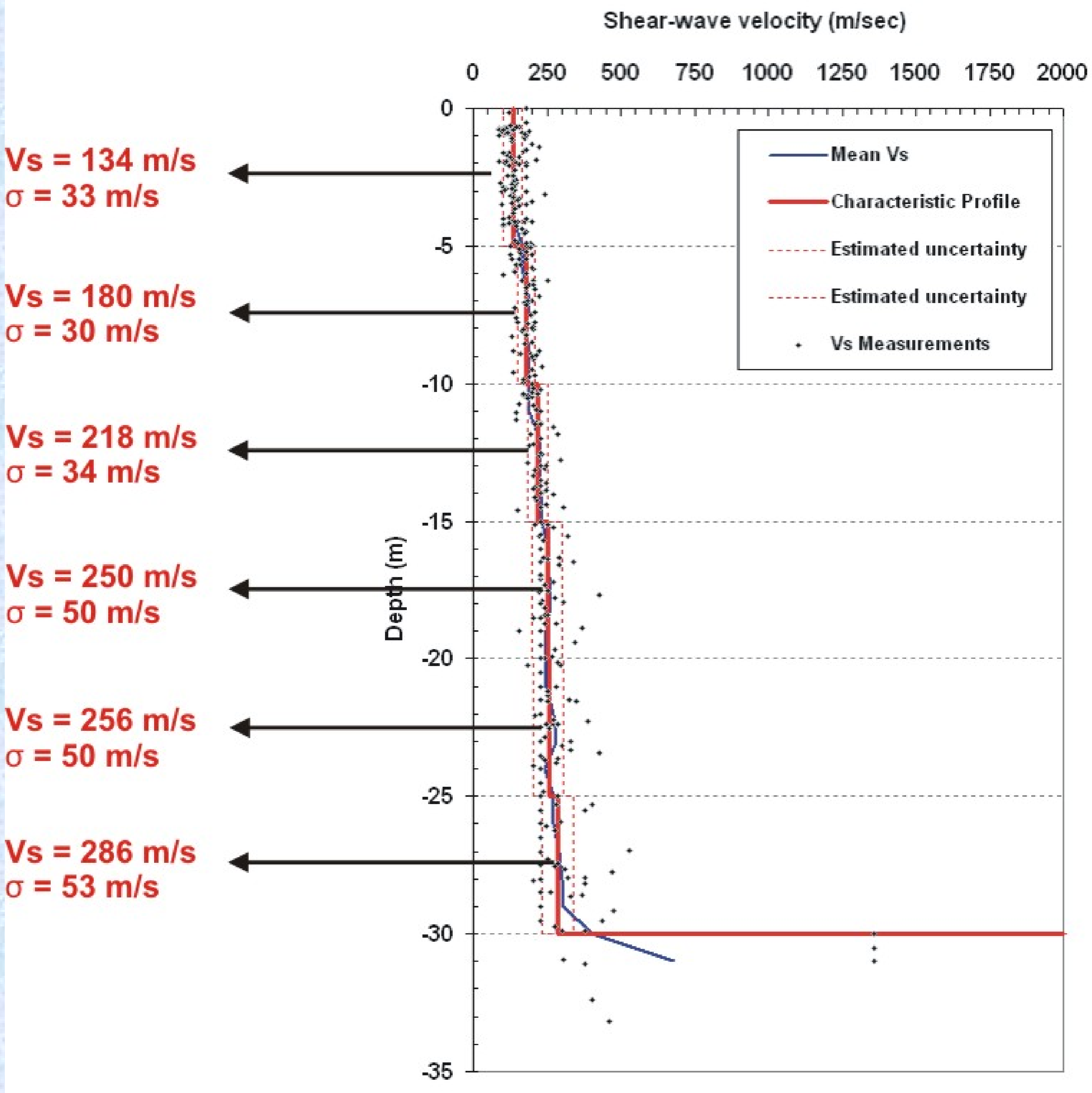
akes:
siness
1, 2008



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

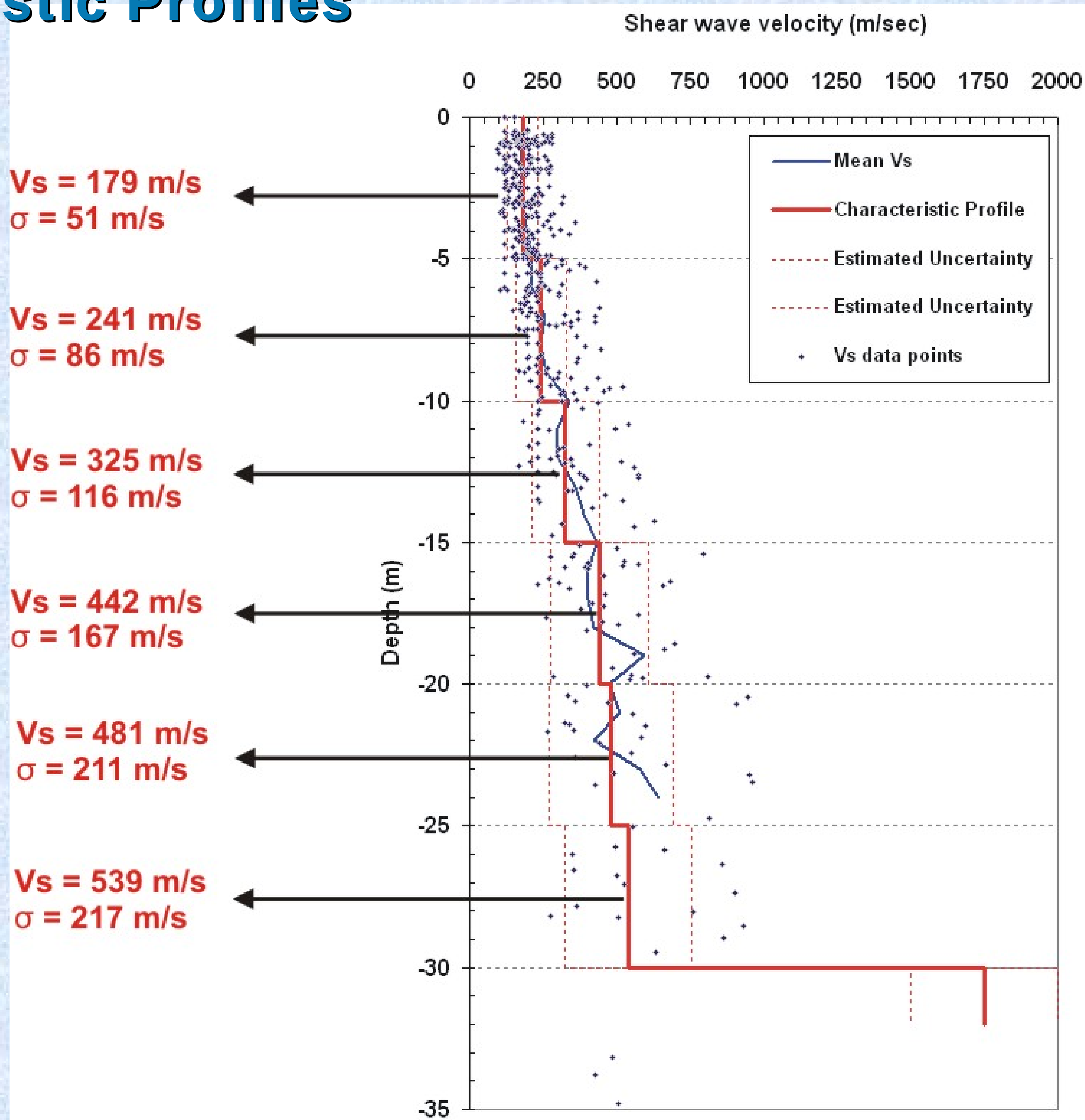
Characteristic Profiles

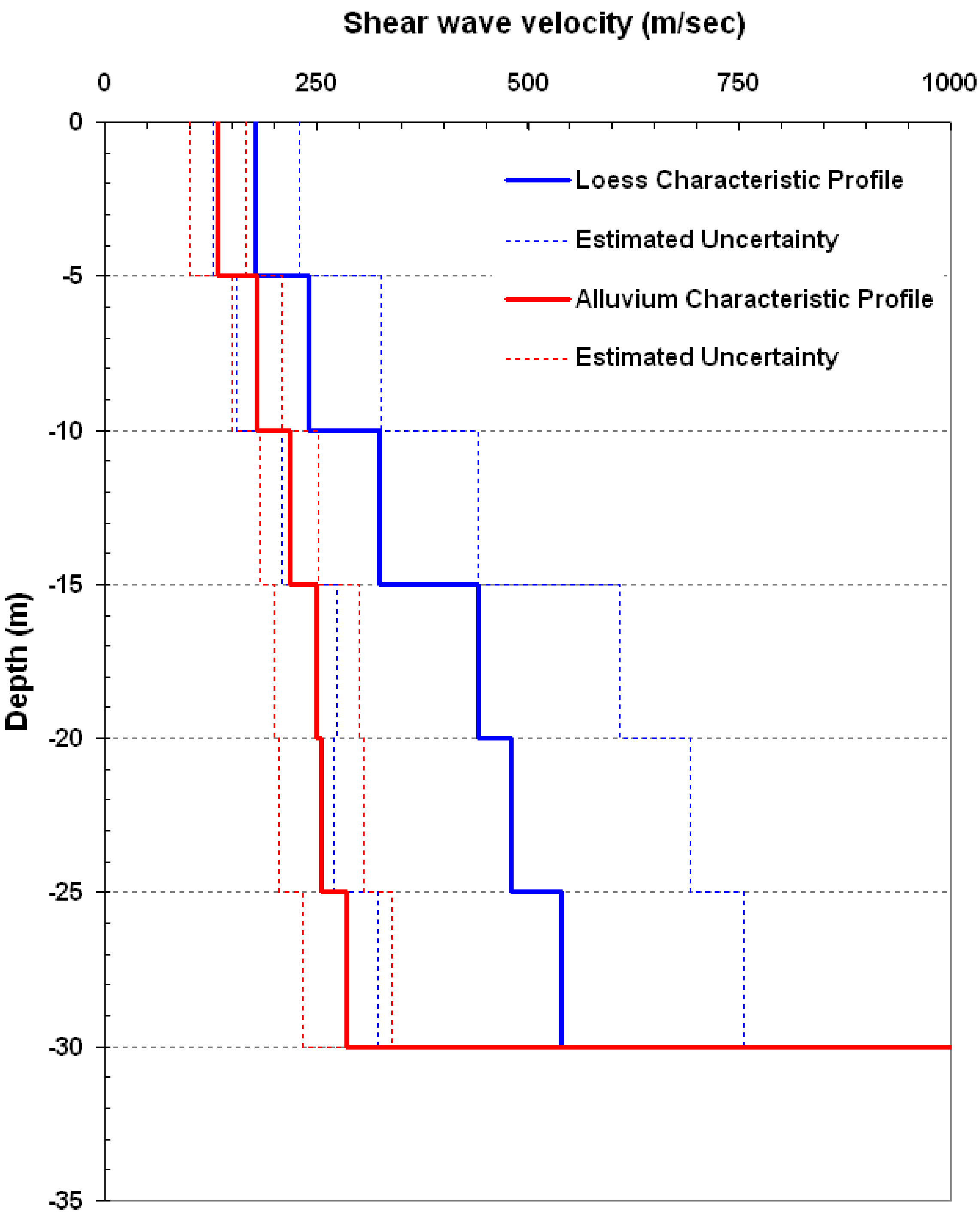
Floodplain (Alluvial) deposits



Characteristic Profiles

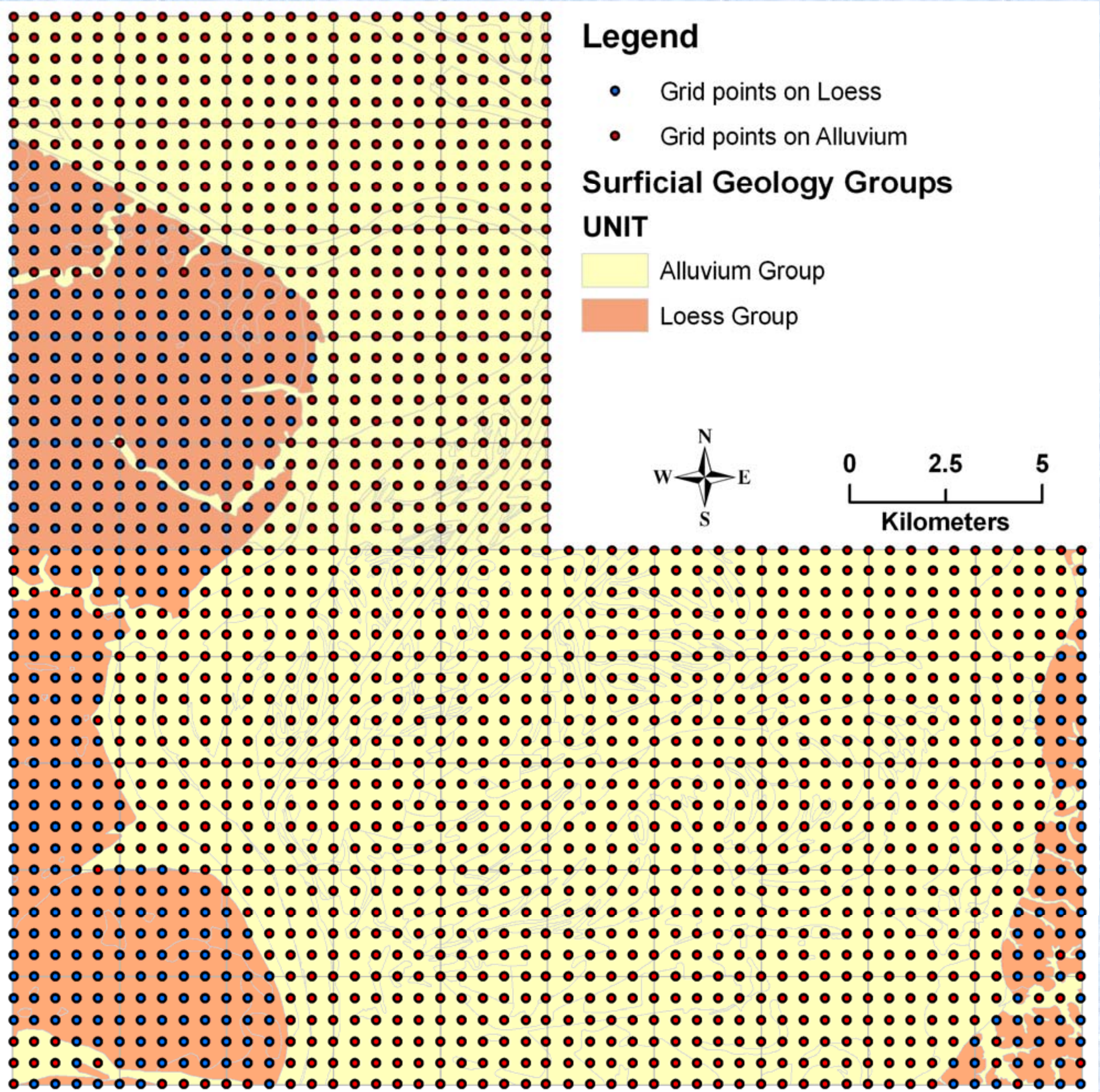
Loess covered Upland deposits





Alluvium vs. Loess

Amplification Calculation Procedure



Total of 1,974 grid points, 500 m apart

For every grid point, calculations were performed 100 times for the 10 ground-motion levels and three ground motion parameters (PGA, 0.2sec Sa, and 1 sec Sa), bringing the total to 3000 calculations per grid point.

When multiplied to the total number of grid points, more than 5,400,000 calculations were made.

Distribution of Site Amplification

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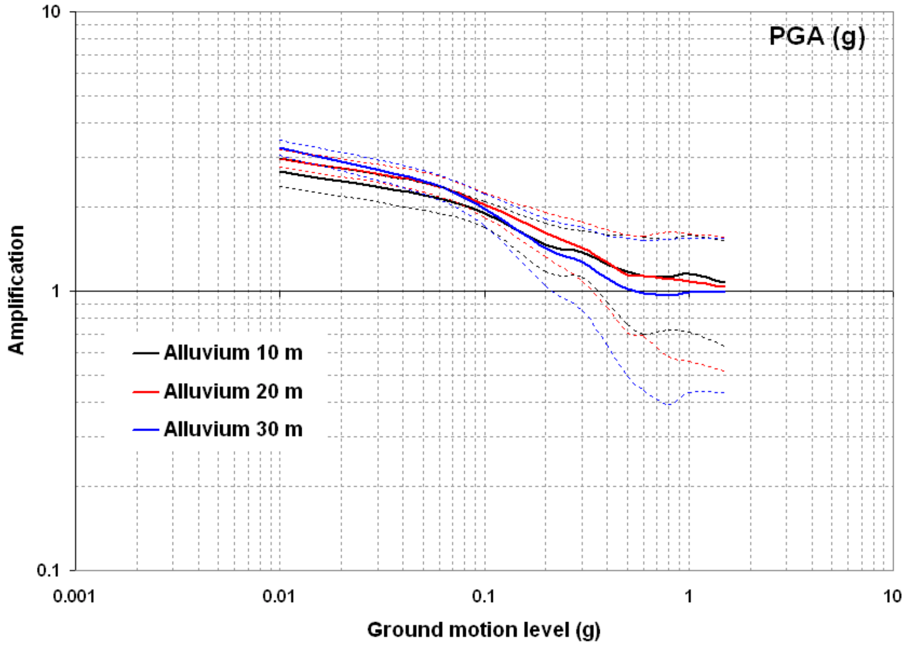
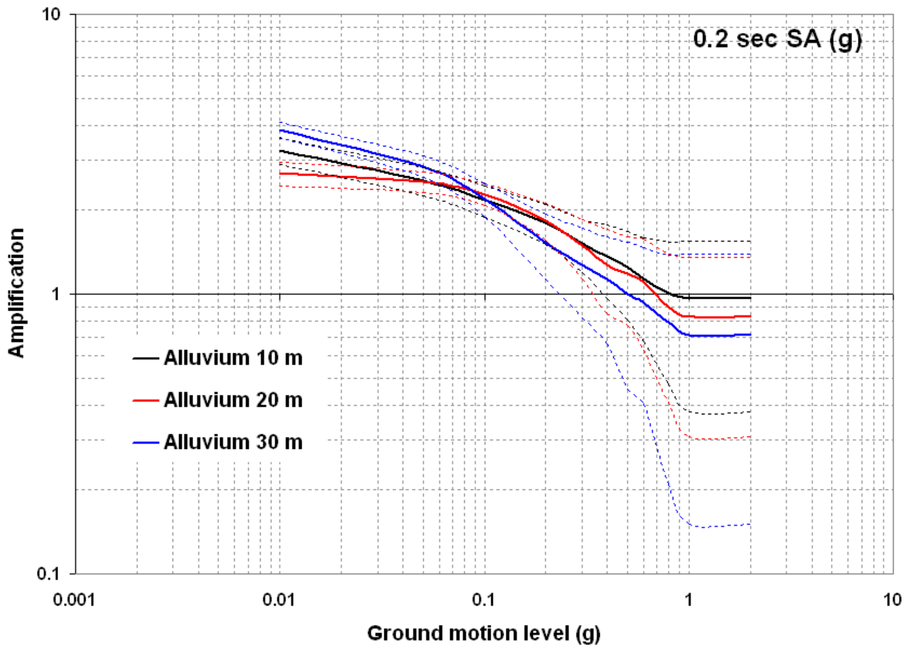
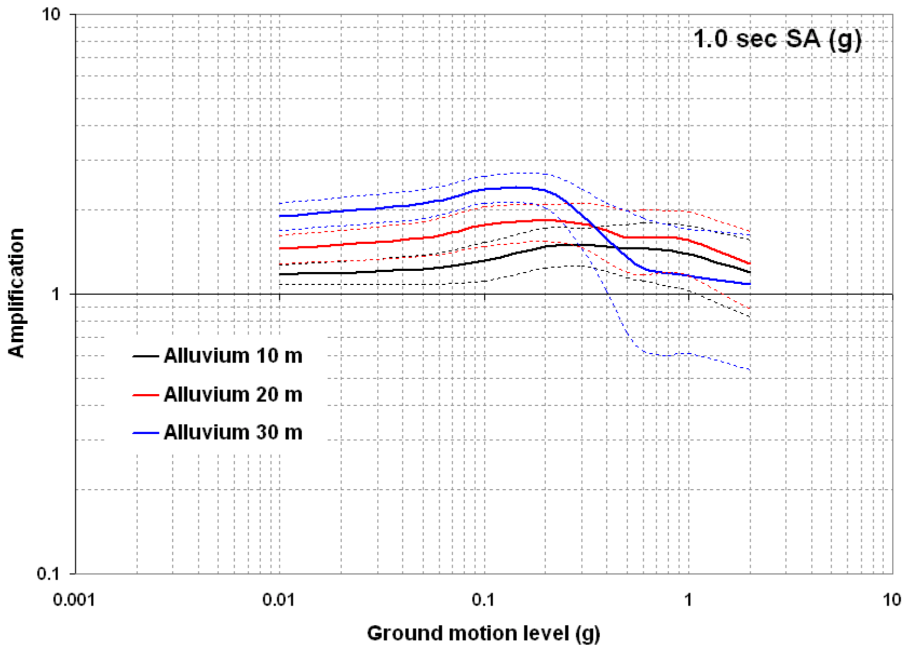
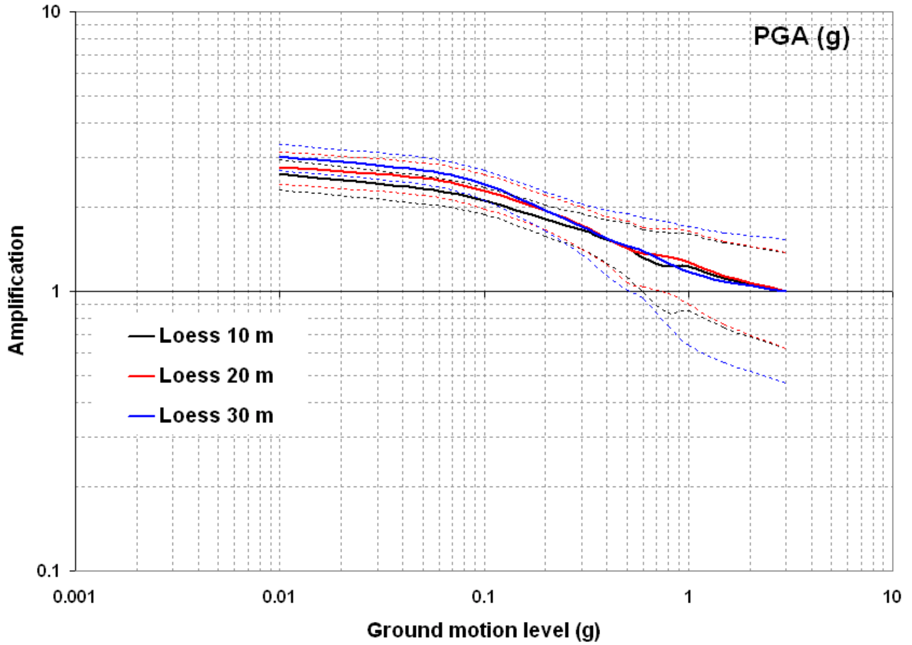
Distribution of Site Amplification in Alluvium

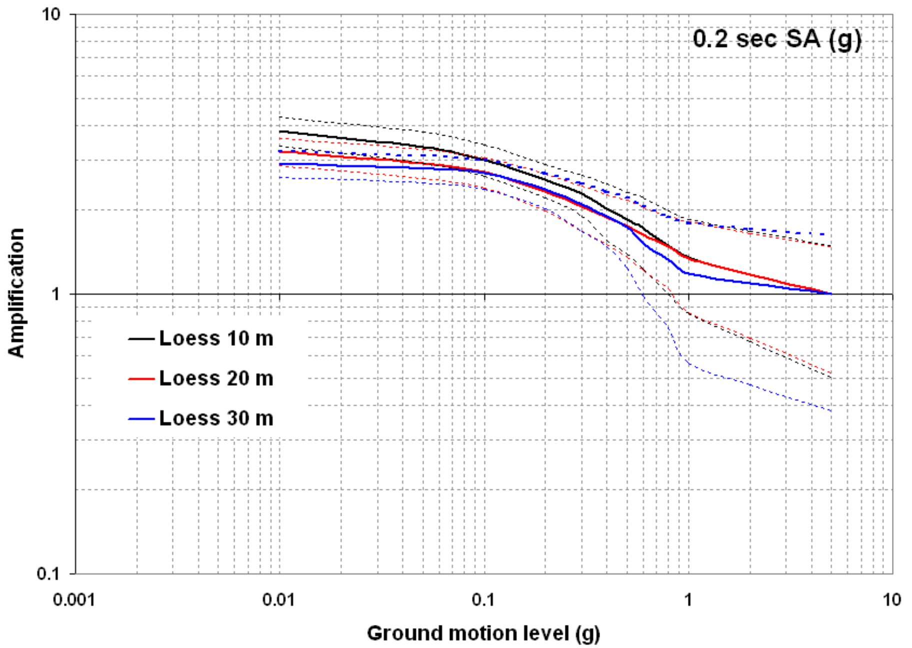


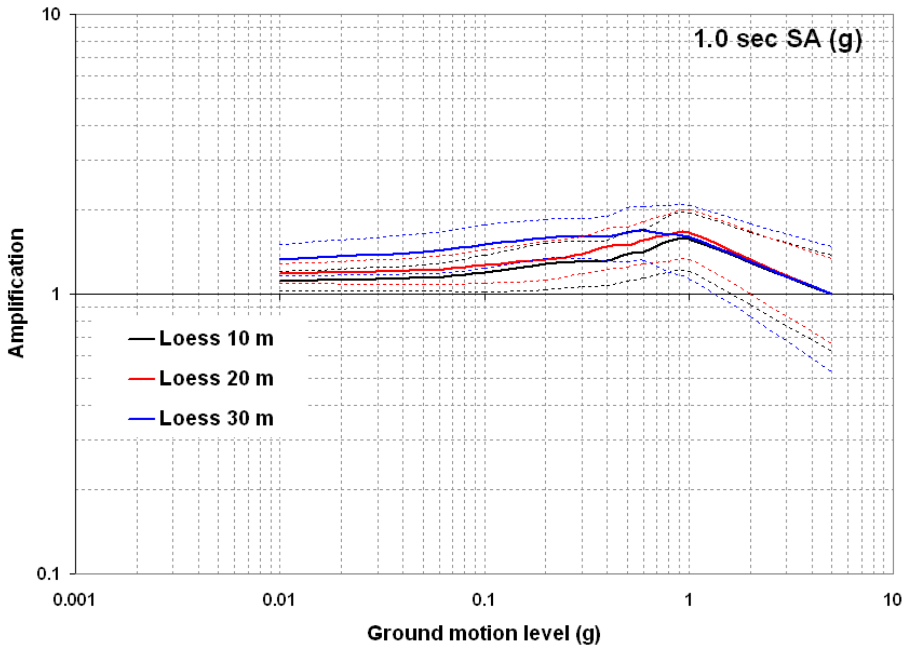




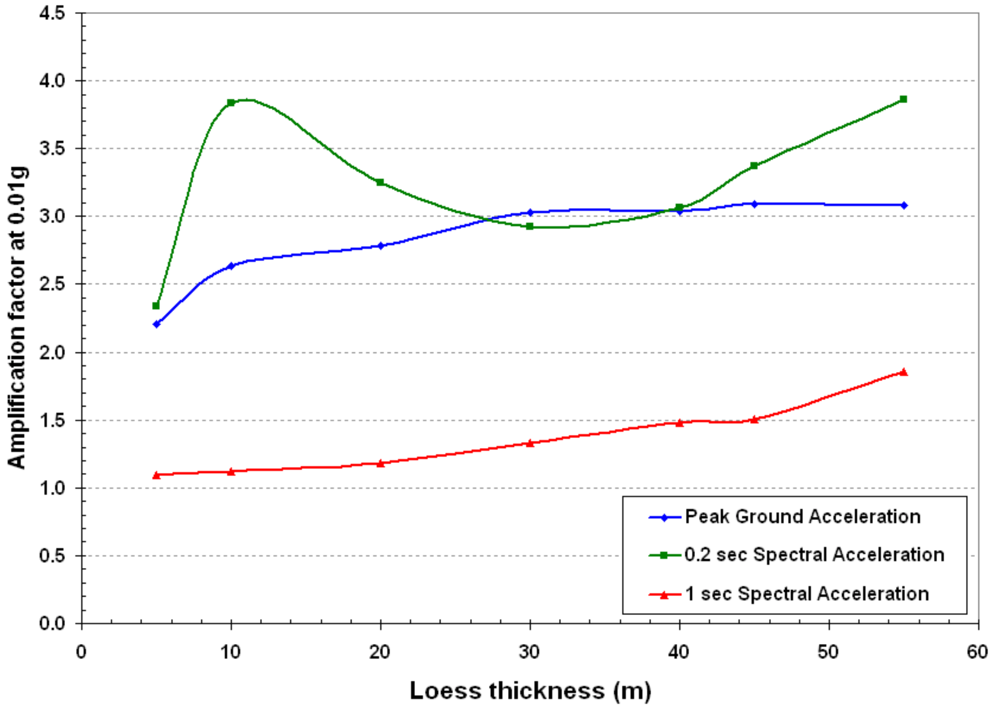
Distribution of Site Amplification in Loess





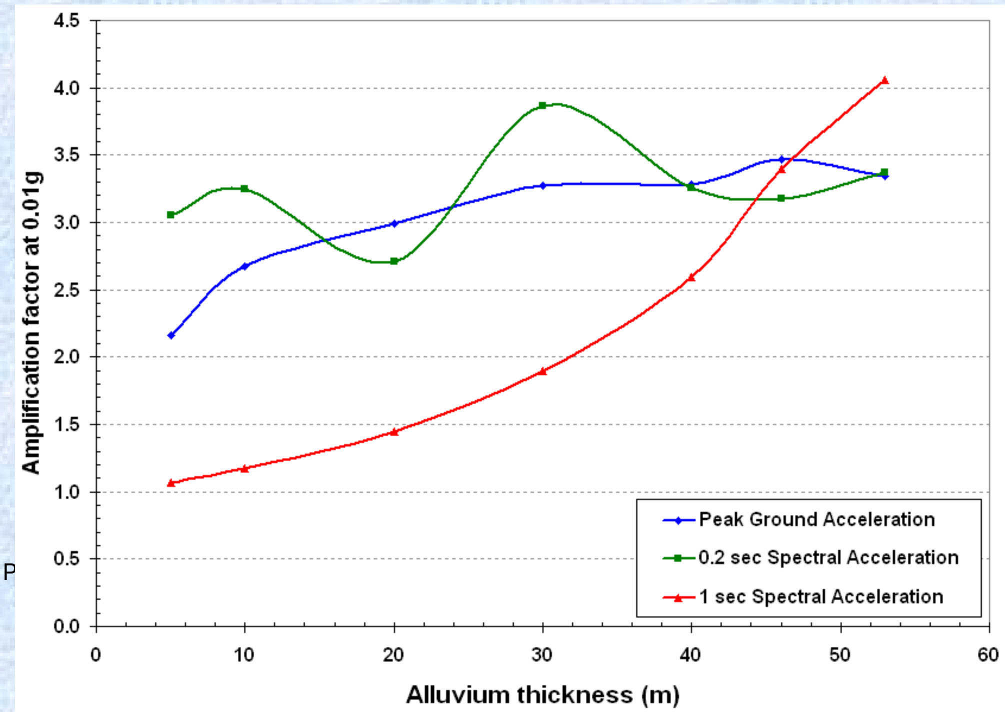


Thickness vs. Ground motion



Upland Profiles

Floodplain Profiles

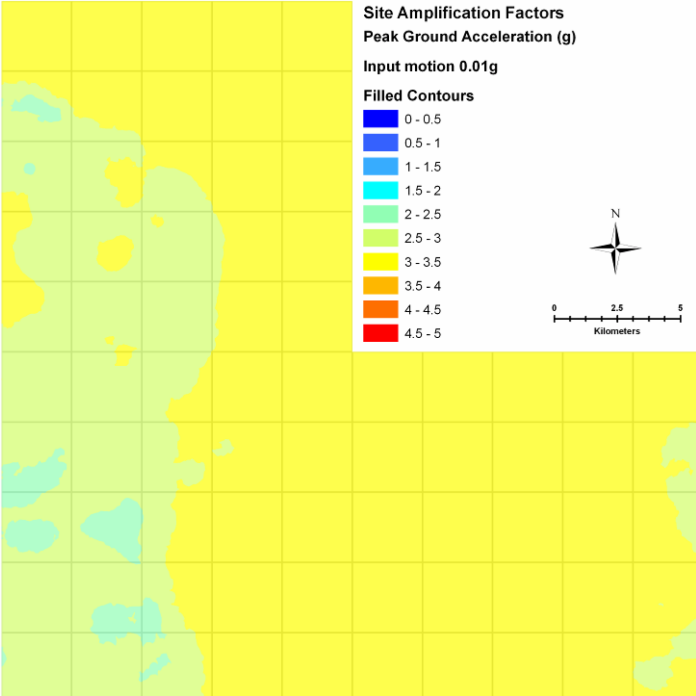


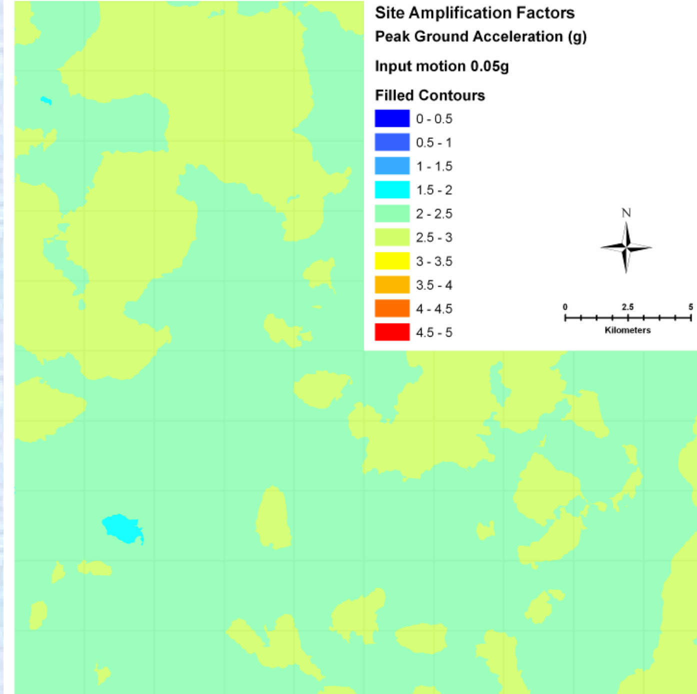
Site Amplification Maps

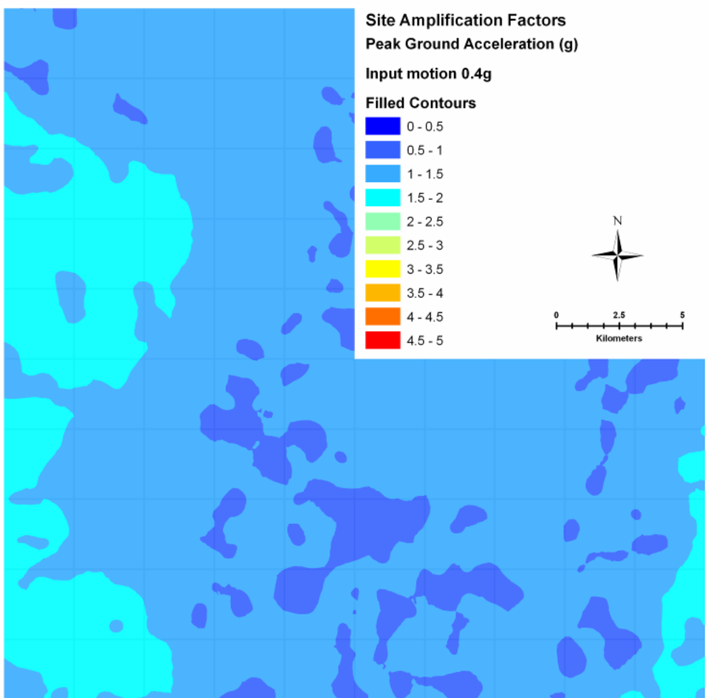
Site amplification maps are generated for every ground motion level of earthquake input and for ground motion parameter :

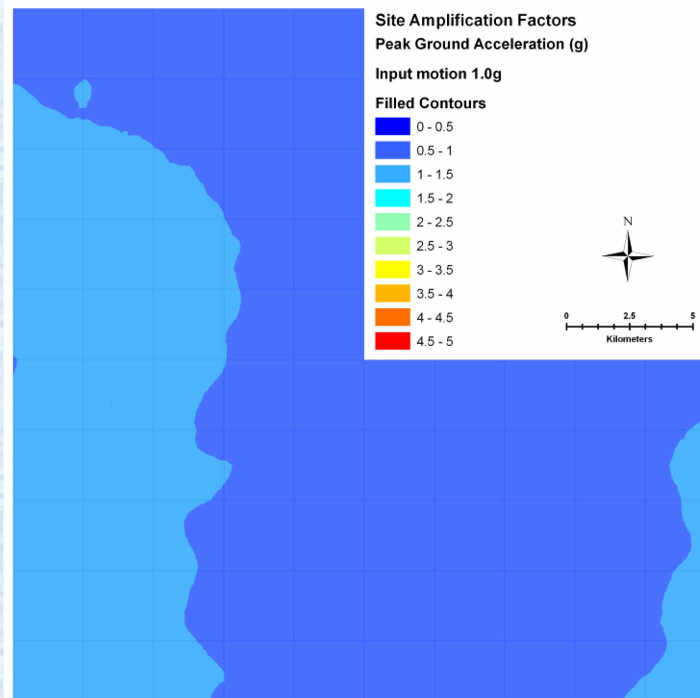
- **Peak Ground Acceleration (PGA)**
- **0.2 sec Spectral Acceleration**
- **1.0 sec Spectral Acceleration**

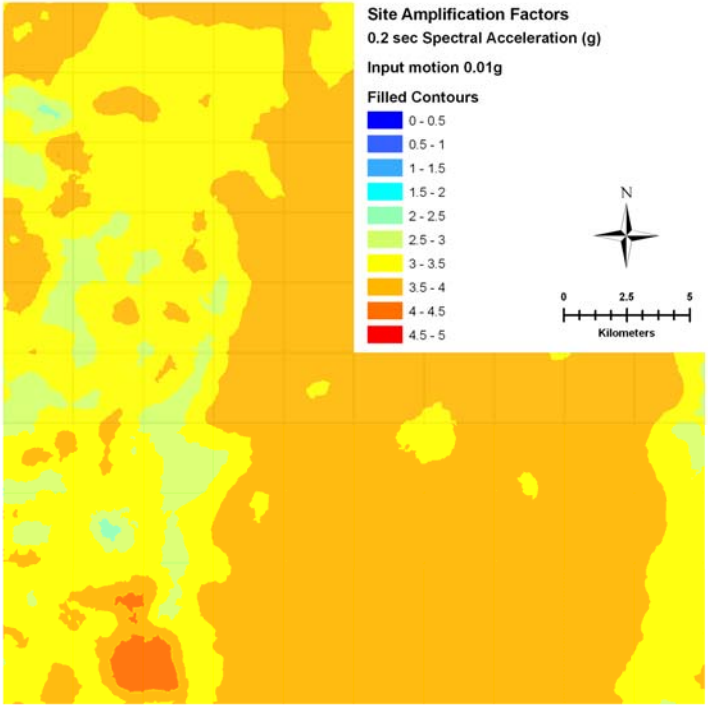
PGA (g)


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

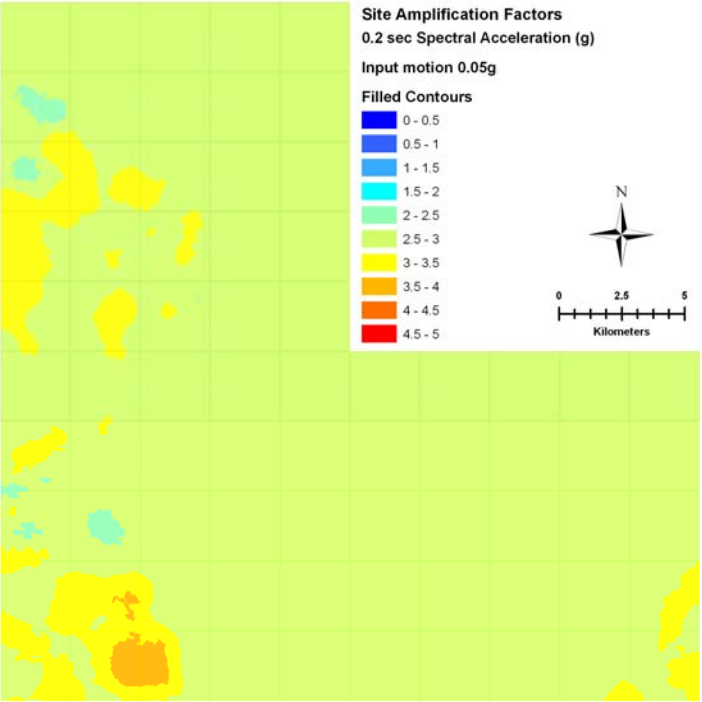

Site Amplification Factors
Peak Ground Acceleration (g)
Input motion 0.05g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

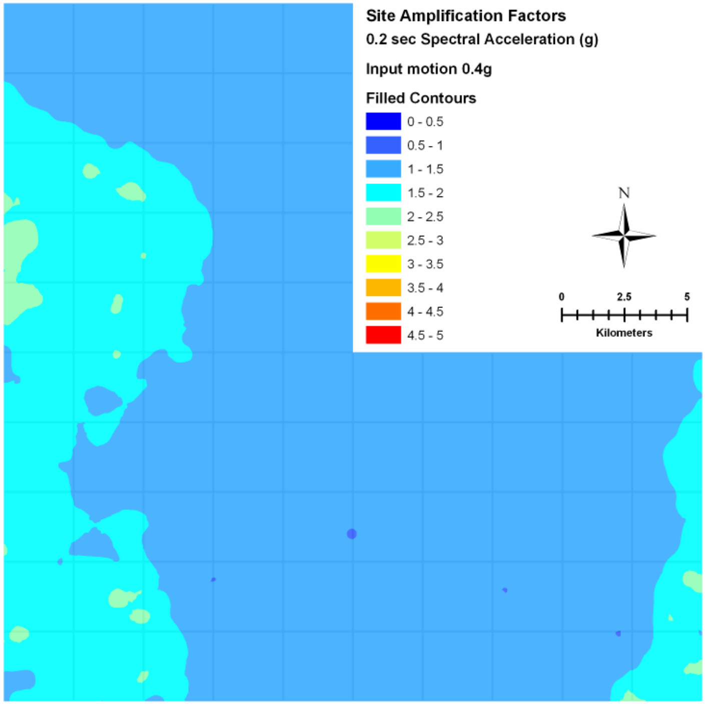

Site Amplification Factors
Peak Ground Acceleration (g)
Input motion 0.4g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

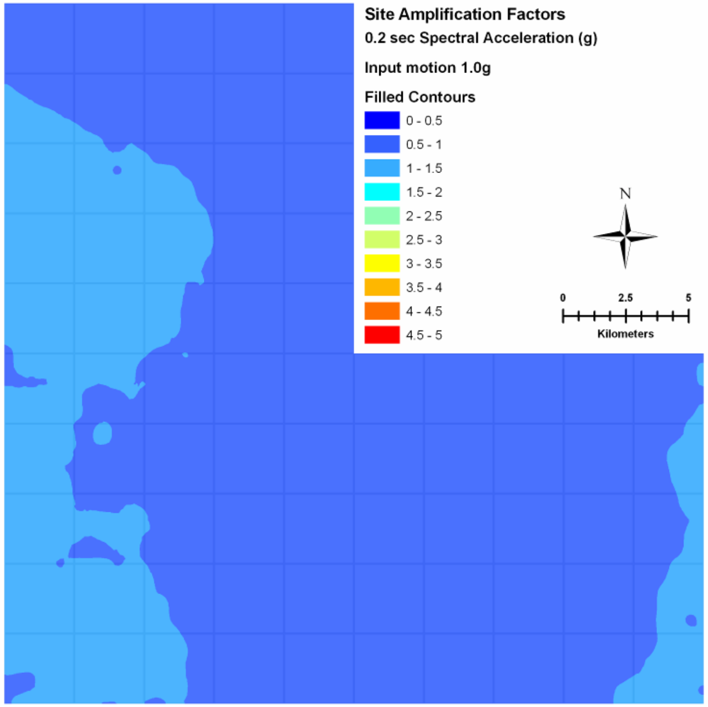

Site Amplification Factors
Peak Ground Acceleration (g)
Input motion 1.0g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0
2.5
5
Kilometers

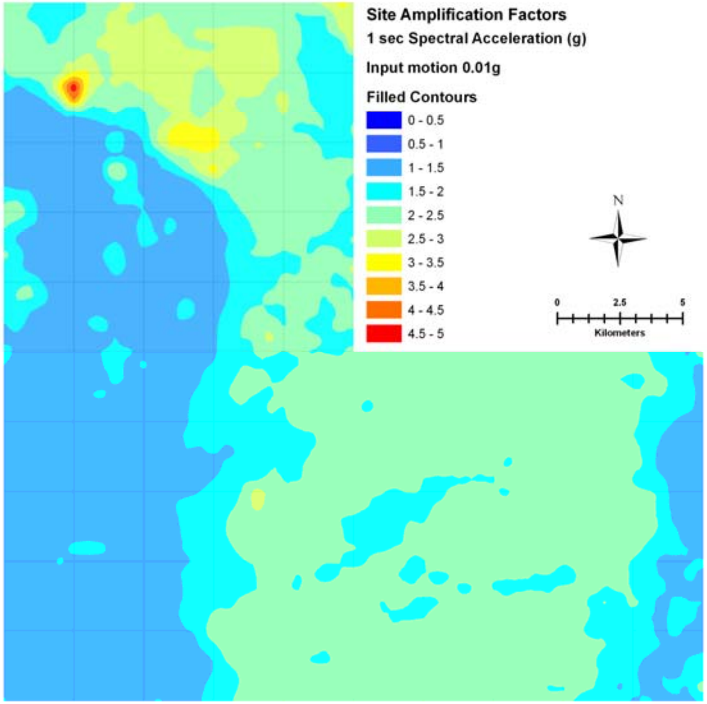

Site Amplification Factors
0.2 sec Spectral Acceleration (g)
Input motion 0.01g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0 2.5 5
Kilometers

0.2 sec SA

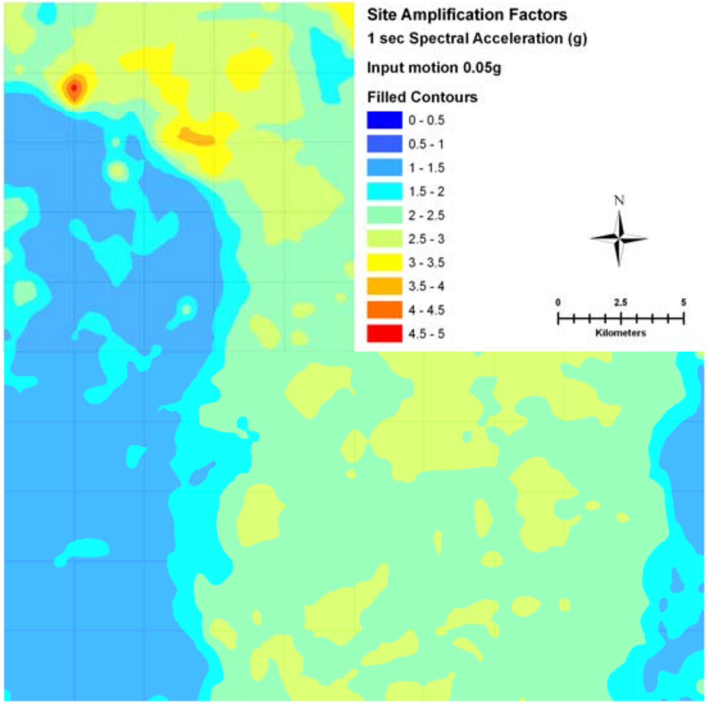

Site Amplification Factors
0.2 sec Spectral Acceleration (g)
Input motion 0.05g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0 2.5 5
Kilometers

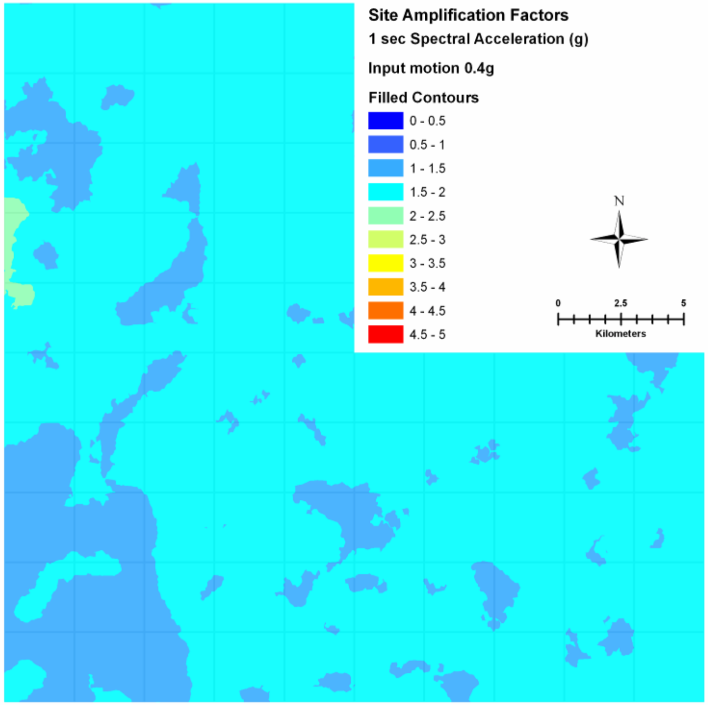

Site Amplification Factors
0.2 sec Spectral Acceleration (g)
Input motion 0.4g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0 2.5 5
Kilometers

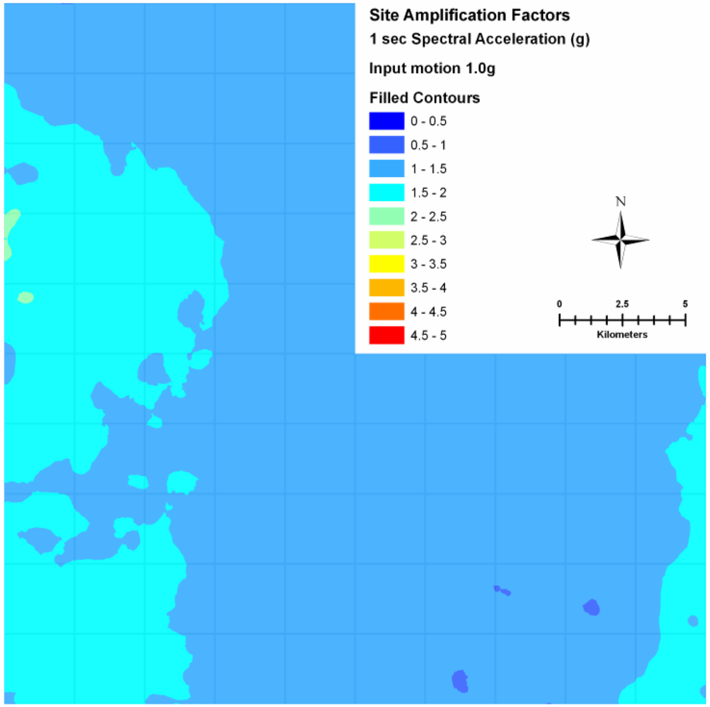

Site Amplification Factors
0.2 sec Spectral Acceleration (g)
Input motion 1.0g
Filled Contours
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
N
0 2.5 5
Kilometers


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

1.0 sec SA


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

Summary of Results

Site amplification depends on level of input motion induced.

Site amplification depends on the distinct geologic characteristics.

Site Amplification is most severe on upland sites underlain by loess.

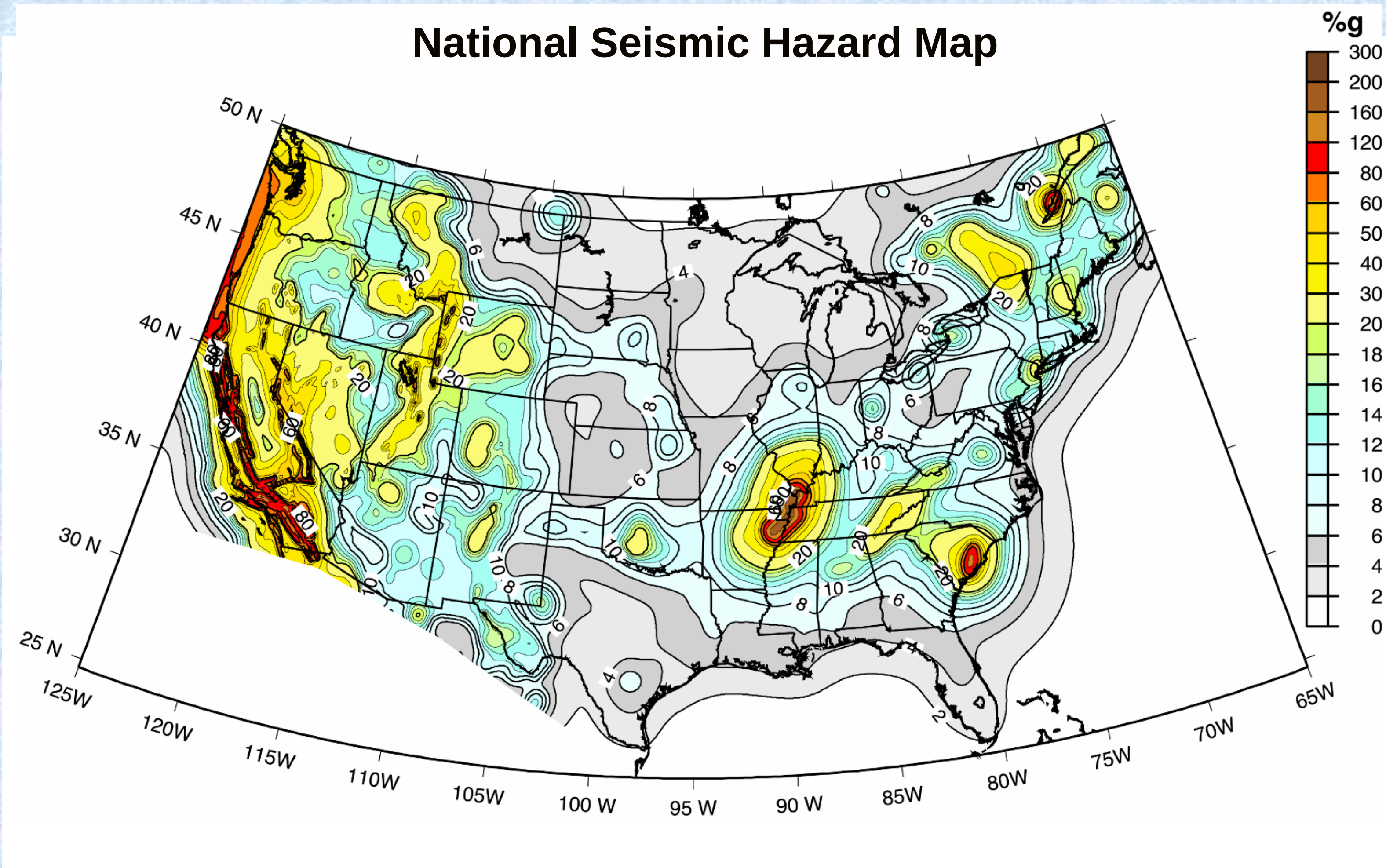
Site Amplification is also most severe for long period structures on deep (>~20 m) alluvial sites, in the natural flood plains.

Seismic Hazard Maps

Previous Examples:

- National Seismic Hazard Maps (2002)
- Memphis Shelby County Seismic Hazard Maps (2004)

The National Seismic Hazard Maps were constructed using the best earth science information available.



However, they do NOT include the effects of local soils, or so-called "site effects"

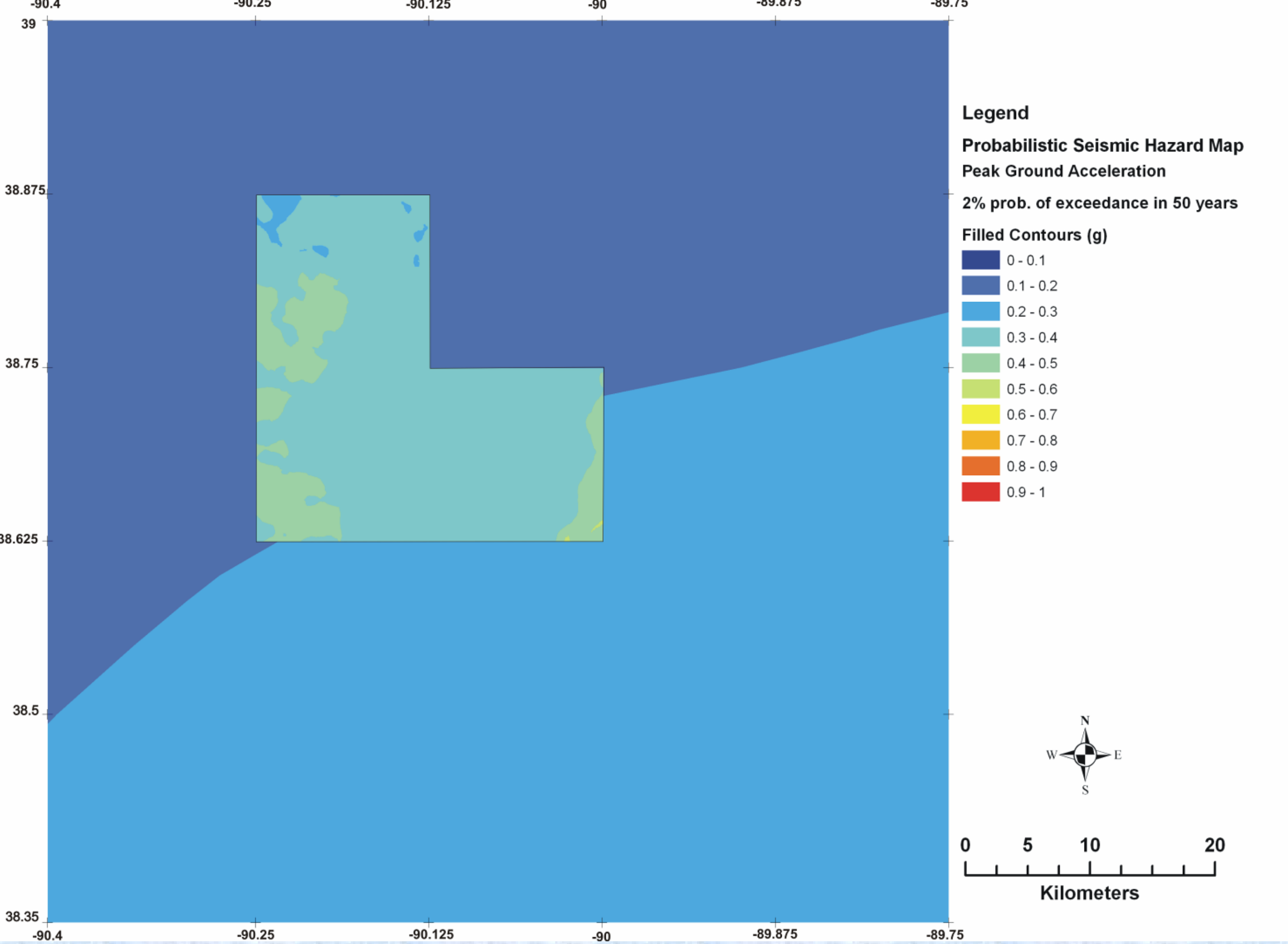
Urban Seismic Hazard Maps (Memphis and St Louis)

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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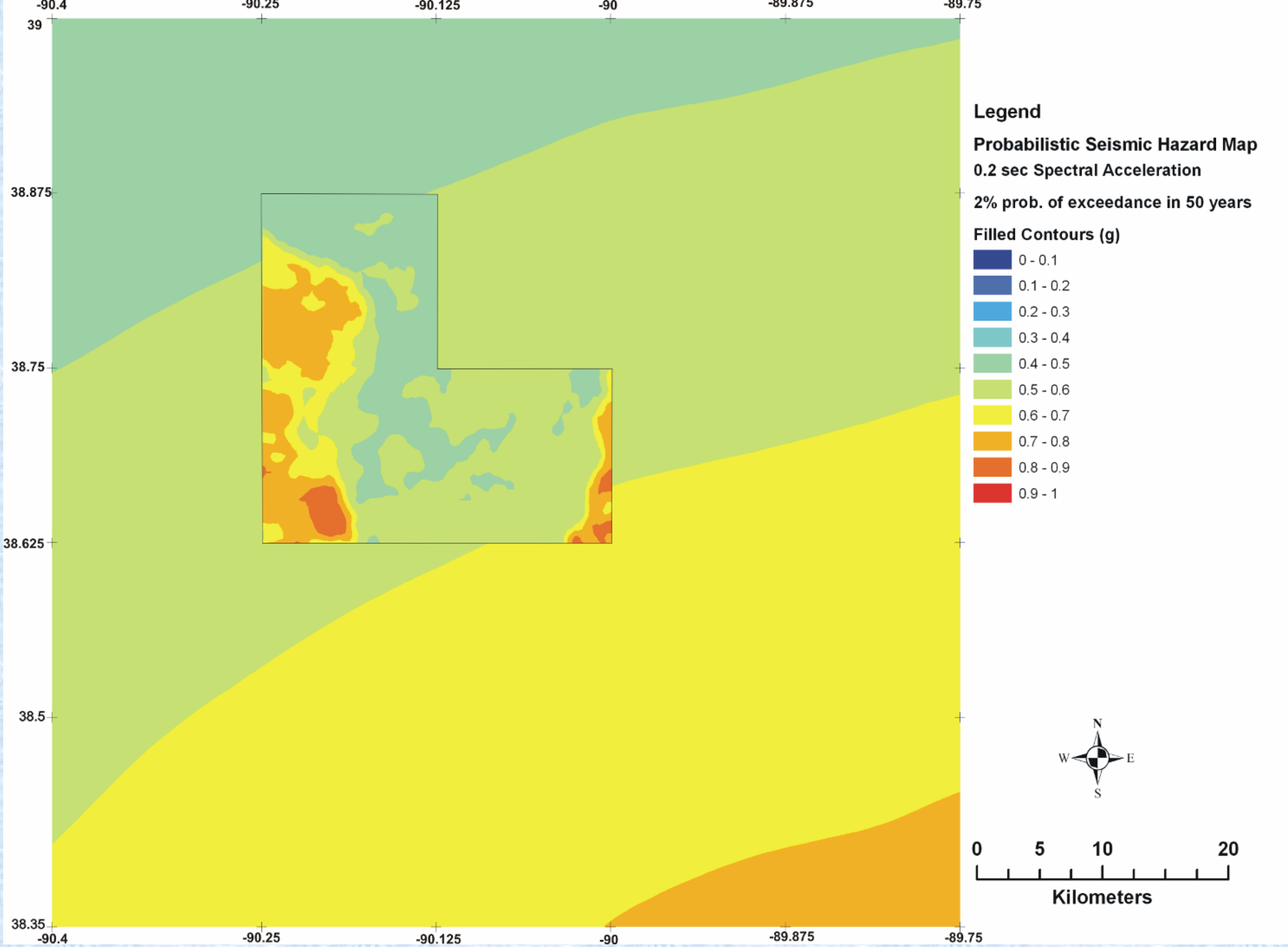

MS&T study vs. USGS National Map (2002)

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

Earthquakes: Mean Business
February 1, 2008

Summary of Results

2% probability of exceedance in 50 years acceleration values for loess at 0.2 sec Sa and for alluvium at 1 sec Sa values appear to be large enough to cause structural damage in the St. Louis Metro Area.

Earthquake forces may be most severe for short period structures, on upland sites underlain by loess.

Earthquake forces may also be severe for long period structures on deep (>14 m) alluvial sites, in the natural flood plains.

Recommendations - 1

The results indicate that the site amplification on alluvial sites is most influenced by the **unit thickness**. Therefore, more data is needed to better define the variations of thickness in alluvium.

The **depth to top-of-bedrock** (soil cap thickness) map was prepared using kriging methods. There are inherent advantages and disadvantages associated with this methodology. Every effort should be made to amend this map with additional data and hand-estimate the bedrock topography, in lieu of kriging, to elicit a more accurate prediction (ignoring 3D effects).

Recommendations - 2

Site amplification and seismic hazard depend largely on the estimated input parameters.

Some of these parameters must be estimated more accurately, i.e., maps showing thickness of the soil cap.

The hazard results are based on the 2002 USGS model. The USGS will be updating their models and the National Map sometime in 2008. New calculations will have to be performed to evaluate how these changes will compare with the estimates in this study.

Acknowledgments

Grants from the U.S. Geological Survey-National Earthquake Hazard Reduction Program and the USGS Central-Eastern U.S. office

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Central United States Earthquake Consortium

Missouri DNR-Division of Geology and Land Survey

Professor Chris Cramer at the University of Memphis

St. Louis Area Earthquake Hazard Mapping Program Technical Working Group and

Phyllis Steckel, RG – facilitator

Dr. Deniz Karadeniz, Dr. Jae-won Chung, Ece Karadeniz, and David J. Hoffman of the MS&T research team

This lecture will be posted at:
http://web.mst.edu/~rogersda/nmsz/