Surficial Geologic and Liquefaction Susceptibility Mapping in Shelby County, Tennessee

Award Number: 00HQGR0031

Principal Investigators: Roy Van Arsdale and Randel Cox

The University of Memphis
Department of Earth Sciences
Memphis, Tennessee 38152

Telephone: 901-678-2177
FAX: 901-678-2178
Email: rvanrsdl@memphis.edu

Program Element: 1

Key Words: Geologic mapping, Liquefaction, Surficial deposits, Memphis

Abstract

Geologic maps were made of the Northeast Memphis, Ellendale, and Germantown 7.5' quadrangles (1:24,000) in Shelby County, Tennessee. Liquefaction susceptibilities were then assigned to the mapped geologic units based on previously published empirical data. Liquefaction susceptibility determinations from borehole blow count data for this same area strongly supports the geology based liquefaction susceptibility maps. However, the geologic maps provide greater detail. The geology based liquefaction susceptibility maps, supported by geotechnical data, appear to be a valuable contribution to liquefaction hazard maps in Shelby County, Tennessee.

Introduction

The city of Memphis and Shelby County, Tennessee, are located approximately 50 km southeast of the New Madrid seismic zone (NMSZ), the most hazardous seismic zone in the eastern United States (Johnston and Schweig, 1996) (Fig. 1). Thus, Shelby County and the city of Memphis are exposed to significant seismic hazards. Due to extensive development in the twentieth century, Memphis and Shelby County have become one of the largest urban areas in the south and is the largest distribution center in the United States. A large earthquake occurring anywhere within the NMSZ could cause widespread loss of life, and damage to buildings, bridges, and lifelines in the Memphis area due to ground shaking and soil liquefaction.

Seismologic and engineering studies have been conducted to assess the expected ground motion in Shelby County (Sharma and Kovacs, 1980; Hwang et al., 1990; Hwang and Lin, 1997) and liquefaction susceptibility (Ng et al., 1989; Chang et al., 1991; Hwang and Lee, 1992; Tarr and Hwang, 1993; Hwang and Lin, 1997; Hwang et al., 1999) in the event of a large New Madrid earthquake. The most comprehensive liquefaction susceptibility studies of Memphis and Shelby County have been conducted by Ng et al. (1989), Hwang and Lin (1997), and updated by Hwang et al. (1999). Ng et al. (1989) and Hwang and Lin (1997) made liquefaction susceptibility maps of Shelby County by compiling soil boring data. They averaged geologic data, water table depth, and blow count values for all borings within 3 x 3 second cells (approximately 762 m E-W x 914 m N-S) and assigned a liquefaction susceptibility to each cell based on these geotechnical data. This grid-based map and its update (Hwang et al., 1999) provide general liquefaction information for Shelby County, and access to individual boreholes used in the construction of the map would provide site-specific data. However, the rectangular cells impose artificial boundaries between the map units and do not capture the distribution of sedimentary units in Shelby County that can be achieved with detailed geologic mapping.

Surficial geologic mapping is an effective means of delineating areas prone to seismic hazards. In particular, surficial geology is the most important factor controlling liquefaction susceptibility (Youd, 1991). Youd and Perkins (1978) have shown that by mapping the surface and near-surface geology, liquefaction susceptibility can be qualitatively assessed (Table 1). No county wide, geology-based liquefaction susceptibility maps have been made of Shelby County. In an earlier NEHRP USGS funded project we mapped the geology of the NW Memphis and Collierville 7.5' (1:24,000) quadrangles. From these geologic maps, the empirically derived correlations between surficial geologic materials and relative liquefaction susceptibility of Youd and Perkins (Table 1) were used to generate liquefaction susceptibility maps that were supported by geotechnical data (Broughton et al., 2001).

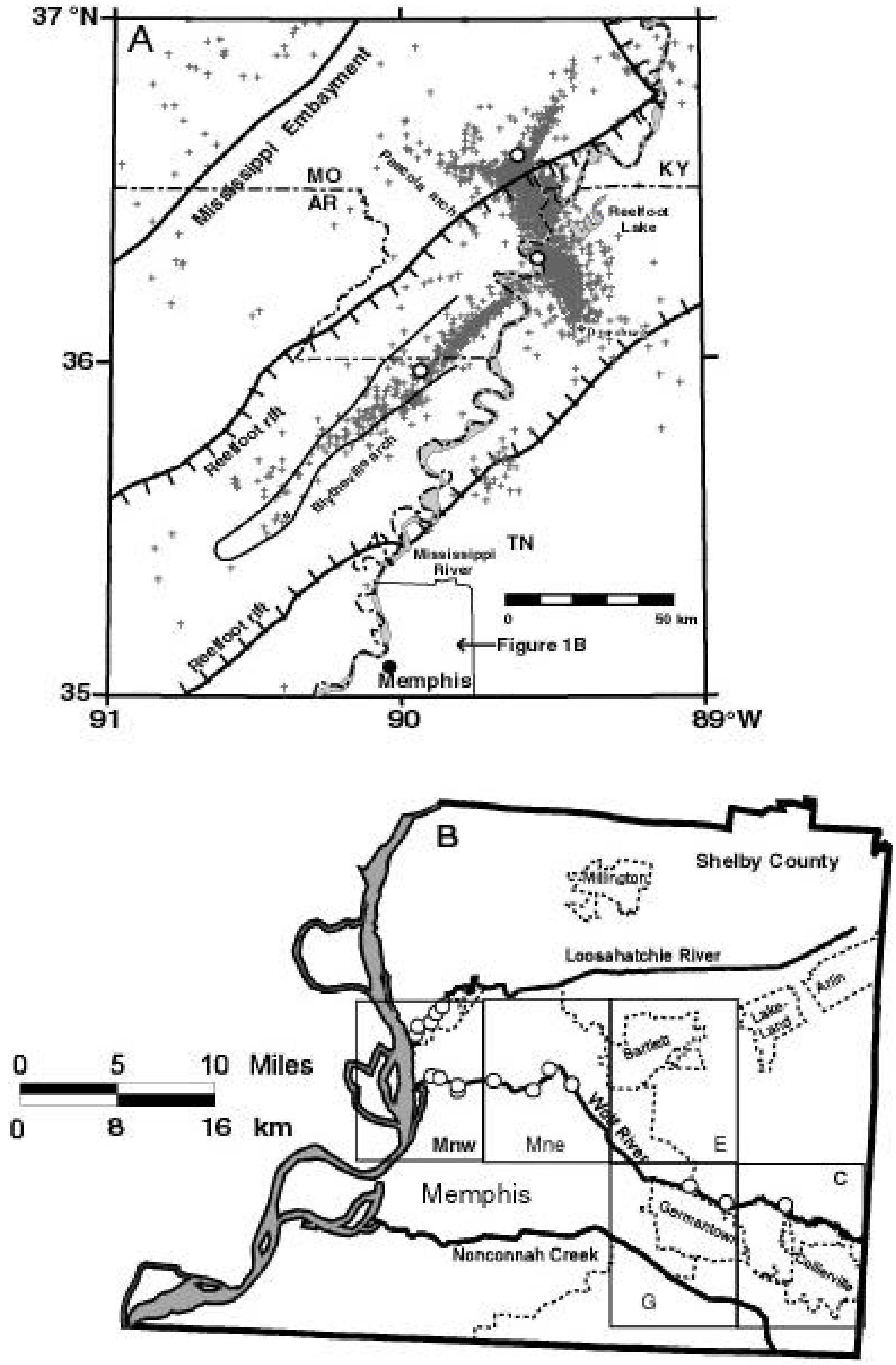


Figure 1. (A) New Madrid seismic zone and Shelby County, TN. + denotes epicenter. (B) 7.5' Quadrangles mapped: Mnw = NW Memphis, Mne = NE Memphis, E = Ellendale, G = Germantown, C = Collierville. o denotes liquefaction deposit.

Table 1. Estimated susceptibility of sedimentary deposits to liquefaction during strong seismic shaking (from Youd and Perkins, 1978).

Type of deposit (1)	General distribution of cohesionless sediments in deposits (2)	Likelihood that Cohesionless Sediments, When Saturated, Would Be Susceptible to Liquefaction (by age of Deposit) <500 yr (3)	Holocene (4)	Pleistocene (5)	Pre-Pleistocene (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
Lacustrine 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	
Tuff	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
(b) Coastal Zone					
Delta	Widespread	Very high	High	Low	Very low
Esturine	Locally variable	High	Moderate	Low	Very low
Beach					
High wave energy	Widespread	Moderate	Low	Very low	Very low
Low wave energy	Widespread	High	Moderate	Low	Very low
Lagoonal	Locally variable	High	Moderate	Low	Very low
Fore shore	Locally variable	High	Moderate	Low	Very low
(c) Artificial					
Uncompacted fill	Variable	Very high	----	----	----
Compacted fill	Variable	Low	----	----	----

Regional reconnaissance along the Loosahatchie and Wolf rivers and Nonconnah Creek identified extensive liquefaction in cut banks of the Wolf River throughout Shelby County and near the mouth of the Loosahatchie River in Memphis (Fig. 1) (Van Arsdale et al., 1998; Broughton et al., 2001). Thus, we determined that the highest mapping priority should be along the Wolf River since its flood plain has liquefied in the past, it flows through the middle of Shelby County, and its flood plain is extensively developed. Specifically, this current project geologically mapped the NE Memphis, Ellendale, and Germantown 7.5' quadrangles. As was done in the Collierville and NW Memphis maps, we subsequently used empirically derived correlations between surficial geologic materials and relative liquefaction susceptibility (Youd and Perkins, 1978) (Table 1) to make our liquefaction susceptibility maps and overlaid the geotechnical data of Hwang et al. (1999) (Plate 1).

Geologic and Liquefaction Susceptibility Mapping

The NE Memphis, Ellendale, and Germantown 7.5' quadrangles were geologically mapped at a scale of 1:24,000. Surface geologic units include the Pliocene-Pleistocene Lafayette Formation (Upland Gravel) (Autin et al., 1991), Pleistocene (Late Wisconsin Finley) loess covered river terraces (Rodbell, 1996), Pleistocene loess (Markewich et al., 1998), silt dominated Holocene flood plain alluvium, sand with overlying silt Holocene flood plain alluvium, and artificial fill.

We have mapped the Lafayette Formation, loess covered uplands, and the loess covered terraces as being of low liquefaction susceptibility. The Lafayette Formation consists of sand and gravel that is locally cemented by iron oxides and is probably of Pliocene age (Potter, 1955). We have found no evidence of liquefaction within the loess, probably because of its high and dry position in the landscape and relatively high (8.5%) clay content (Spann, 1998). The terraces are Pleistocene in age and are also overlain by the low susceptibility loess. The flood plains of the Mississippi, Wolf, and Loosahatchie rivers consists of a basal point bar sand sequence overlain by overbank silty clay (Mississippi) or clayey silt (Wolf and Loosahatchie). Liquefaction deposits have been identified in cut banks of the Wolf River throughout the entire map area of Plate 1 and near the mouth of the Loosahatchie River. Thus, we have mapped this sand and silt Holocene alluvium as being of very high liquefaction susceptibility. No liquefaction was found along Nonconnah Creek or its tributaries or along any tributaries to the Wolf or Loosahatchie rivers. Thus, we conclude that the limited amount of sand in these silt-dominated Holocene flood plains make them a low liquefaction susceptibility unit.

The artificial fill unit is difficult to assign liquefaction susceptibility since we do not know the composition of this unit. It appears that most of the fill is locally derived. Artificial fill throughout much of the map area is designated as being of moderate liquefaction susceptibility because we believe those fills are predominantly made of silt and they sit on silt flood plains (Plate 1). However, borrow pits along the Wolf River have excavated silt and sand and thus many of the fill sites along the Wolf River probably have a high sand content. Whether this sand is mixed with the silt or exists as distinct clean layers that may liquefy is not known. In addition, fill has locally been put on the Wolf River flood plain and the flood plain has liquefied in the past. Thus, we have mapped artificial fill on the Wolf River flood plain as being of high liquefaction susceptibility (Youd and Hoose, 1977). We have also included Mud Island in this category because the artificial fill on Mud Island was dredged from the Mississippi River, the fill sits on a historical sand bar (Georgia Tech Research Corporation, 2000).

Comparison of the Liquefaction Susceptibility Maps with Geotechnical Data

Geotechnical data have been collected and synthesized from over nine thousand engineering borings in Shelby County (Hwang et al., 1999). Hwang et al. (1999) have labeled a boring site as likely to liquefy during an earthquake if (1) sand layer depth is <20m, (2) water table depth is <10m, and (3) the SPT-N (blow count) value is <20. Based on these criteria, Hwang et al. (1999) mapped the areas of Shelby County susceptible to liquefaction. Upon superimposing the Hwang et al. (1999) data onto our liquefaction susceptibility map (Plate 1), close agreement is apparent. Areas of liquefaction susceptibility occur along the Mississippi, Loosahatchie, and Wolf river flood plains. Most of the discrepancies occur along the edges of these flood plains. We believe this is because the averaged rectangles of Hwang and Lin (1997), retained in Hwang et al. (1999), often straddle these boundaries.

Conclusions

Liquefaction has occurred in the city of Memphis and Shelby County, Tennessee, along sand dominated Holocene flood plains of the Loosahatchie and Wolf rivers probably during the great New Madrid earthquakes of 1811-1812 (Broughton et al., 2001). We suspect that liquefaction also occurred along the Mississippi River, but the surface Mississippi River flood plain sediments in this map area post date 1811-1812. Thus, it is reasonable to assume that future earthquakes of comparable magnitude will produce liquefaction in these flood plains. In a previous study, we determined that the Wolf River flood plain is particularly susceptible to liquefaction and mapped the NW Memphis and Collierville 7.5 quadrangles at the western and eastern margins of Shelby County (Broughton et al., 2001). In this current study, we geologically mapped the remainder of the Wolf River flood plain in Shelby County in the NE Memphis, Ellendale, and Germantown 7.5' quadrangles. From these geologic maps we constructed liquefaction susceptibility maps (Plate 1) based on the empirical criteria of Youd and Perkins (1978). We have also superimposed liquefaction susceptibility geotechnical data from Hwang et al. (1999) onto the geologic maps. Superposition of the geotechnical data illustrates that the liquefaction susceptibility is controlled by the near surface geology (Plate 1). It is also apparent in Plate 1 that the geologic mapping allows extrapolation beyond and interpolation between the geotechnical borings and thus provides a more detailed liquefaction susceptibility map.

There remain uncertainties in our maps that will require additional research. In particular, the artificial fills' internal compositions should be determined to better assign their liquefaction susceptibilities. Secondly, the Wolf River flood plain has undergone much cut-and-fill since it liquefied in 1811-1812 (Van Arsdale et al., 2003; Yates et al., in press). How flood plain urbanization has affected liquefaction susceptibility also requires additional research. It is also important to point out that portions of these maps are already obsolete as artificial filling and development continues along the Wolf River.

References Cited

Autin, W.J., Burns, S.F., Miller, B.J., Saucier, R.T., Snead, J.L., 1991, Quaternary Geology of the Lower Mississippi Valley. In: Morrison, R.B. (Ed.), Quaternary Nonglacial geology: Conterminous US. GSA, Boulder, CO, p. 547-582.

Broughton, A.T., Van Arsdale, R.B., and Broughton, J.H., 2001, Liquefaction susceptibility mapping in the city of Memphis and Shelby County, Tennessee. Engineering Geology, v. 62, p. 207-222.

Chang, T.-S., Tang, P.S., Lee, C.S., and Hwang, H., 1991, Liquefaction potential in the Memphis area. Proceeding of the Fourth International Conference on Seismic Zonation, Stanford, CA II, p. 459-466.

Gelderloos, D.M., 1996, ESR as a dating technique for the Peoria loess: a preliminary evaluation. MS thesis, University of Memphis, Memphis, Tennessee, 58 p.

Georgia Tech Research Corporation, 2000, Results of seismic piezocone penetration tests performed in Memphis, Tennessee. USGS NEHRP project number E-20-F47/F34 final report.

Hwang, H., Chien, M.C., and Lin, Y.W., 1999, Investigations of soil conditions in Memphis, Tennessee. Technical Report, Center for Earthquake Research and Information, The University of Memphis, Memphis, TN.

Hwang, H., and Lee, C.S., 1992, Evaluation of liquefaction potential in Memphis area, USA. Proceedings of the Tenth World Conference on Earthquake Engineering, Madrid, Spain, p. 1457-1460.

Hwang, H., Lee, C.S., and Ng, K.W., 1990, Soil effects on earthquake ground motions in the Memphis area. Technical report NCEER-90-00209. National Center for Earthquake Engineering Research, State University of New York at Buffalo, Buffalo, NY.

Hwang, H., and Lin, H.J., 1997, GIS-based evaluation of seismic performance of water delivery systems. Technical report. Center for Earthquake Research and Information, University of Memphis, Memphis, TN.

Johnston, A.C., and Schweig, E.S., 1996, The enigma of the New Madrid earthquakes of 1811-1812. Annual Review of Earth and Planetary Sciences, v. 24, p. 339-384.

Markewich, H.W., Wysocki, D.A., Pavich, M.J., Rutledge, E.M., Millard, H.T., Rich, F.J., Matt, P.B., Rubin, M., McGeehin, J.P., 1998, Paleopedology plus TL, ^{10}Be, and ^{14}C dating as tools in stratigraphic and paleoclimatic investigations, Mississippi River valley, USA. Quaternary International v. 51/52, p. 143-167.

Ng, K.W., Chang, T.-S., and Hwang, H., 1989, Subsurface conditions of Memphis and Shelby County. Technical Report NCEER-89-0021, National Center for Earthquake Engineering Research, SUNY, Buffalo, NY.

Rodbell, D.T., 1996, Subdivision, subsurface stratigraphy, and estimated age of fluvial-terrace deposits in northwestern Tennessee. US Geological Survey Bulletin 2128.

Saucier, R.T., 1987, Geomorphological interpretations of late Quaternary terraces in western Tennessee and their regional tectonic implications. U.S. Geological Survey Professional Paper 1336-A, 19 p.

Sharma, S., and Kovacs, W.D., 1980, Microzonation of the Memphis, Tennessee, area. Report to USGS. Department of Civil Engineering, Purdue University, W. Lafayette, IN.

Spann, E.W., 1998, Selected sediment and geochemical properties of Quaternary and Tertiary sediments from five boreholes in Shelby County, Tennessee: implications for contaminant retardation potential. MS Thesis, University of Memphis, Tennessee.

Tarr, A.C., and Hwang, H., 1993, GIS generated seismic hazard maps for Memphis and Shelby County, Tennessee. Proceedings of the 1993 National Earthquake Conference I, p. 173-182.

Van Arsdale, R.B., Broughton, J.H, and Broughton, A.T., 1998, Liquefaction in Memphis Tennessee. American Geophysical Union, v. 17, p. S341.

Van Arsdale, R., Waldron, B., Ramsey, N., Parrish, S., and Yates, R., 2003, Impact of river channelization on seismic risk, Shelby County, Tennessee. Natural Hazards Review, v. 4, n. 1, p. 1-10.

Yates, R., 2002, Geologic setting and Post-1940s Evolution of the Wolf River Flood Plain, Shelby County, Tennessee. MS thesis, University of Memphis, 76 p.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation. Proceedings of the Fourth International Conference on Seismic Zonation I, p. 111-147.

Youd, T.L., and Hoose, S.N., 1977, Liquefaction susceptibility and geologic setting. Proceedings of the Sixth World Conference on Earthquake Engineering, New Delhi, India, v. 6, p. 37-42.

Youd, T.L., and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential. Journal of the Geotechnical Engineering Division, p. 443-446.

Bibliography

Van Arsdale, R., Waldron, B., Ramsey, N., Parrish, S., and Yates, R., 2003, Impact of river channelization on seismic risk, Shelby County, Tennessee. Natural Hazards Review, v. 4, n. 1, p. 1-10.

Yates, R., Waldron, B., and Van Arsdale, R.B., Urban effects on flood plain natural hazards: Wolf River, Tennessee, USA. In press with Engineering Geology.

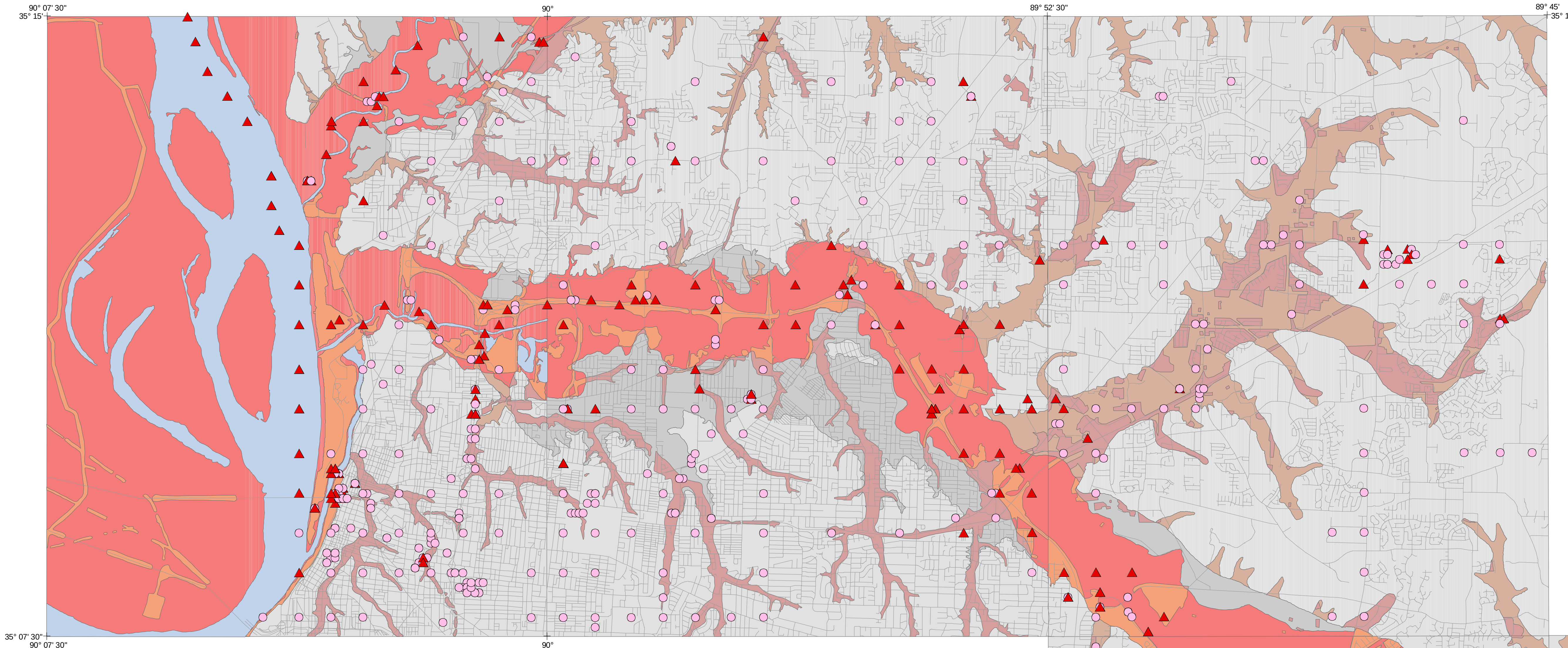
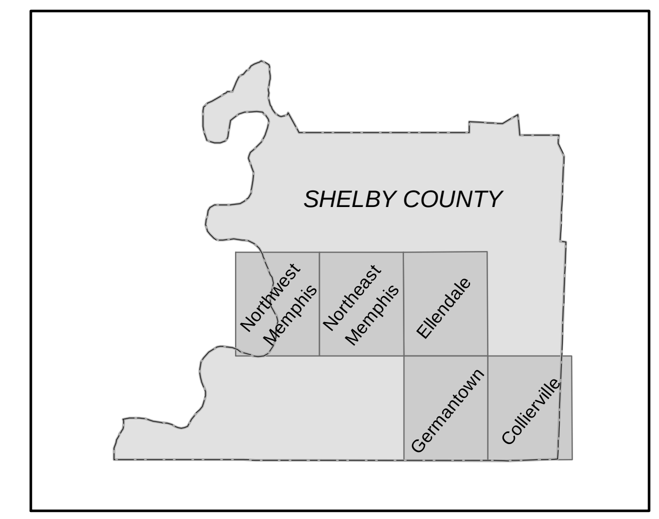
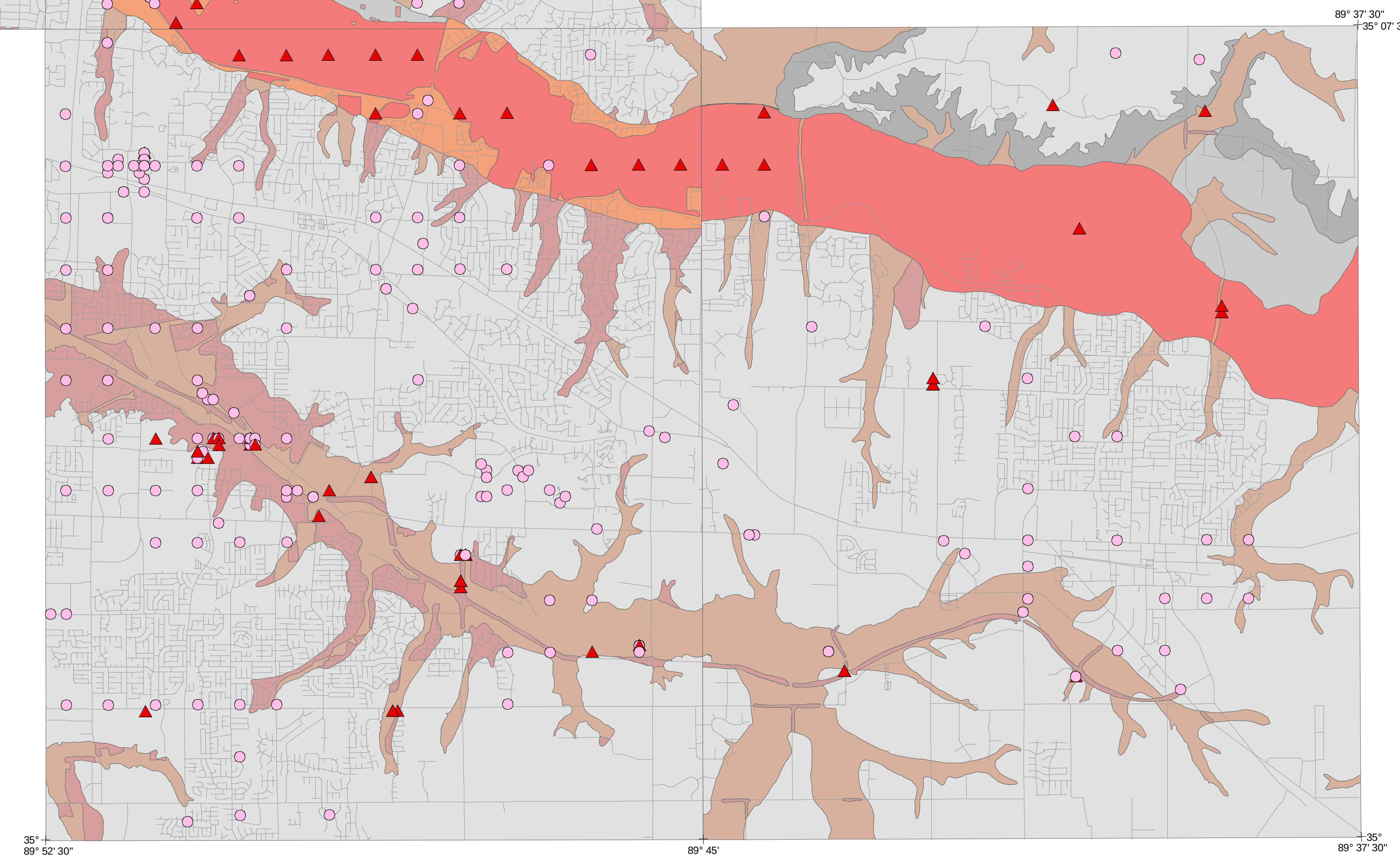


Plate 1
Liquefaction Susceptibility for Five 7.5' Quadrangles along the Wolf River in Shelby County, Tennessee

Roy VanArsdale, Randel Cox, and Kathleen Tucker





Liquefaction Susceptibility	Geologic Units
Very High	Alluvium (Holocene); white (10YR 8/2) sand, brown (10YR 6/2) clayey silt, with minor tan (10YR 7/4) gravel. The sand is very fine to coarse grained quartz with chert. Thick bedded (0.5-1.5 m) basal point bar sands are overlain by alternating thin beds of sand and silt (<0.5 m) and capped by overbank clayey silt with beds < 1 cm thick to having no apparent bedding. The bottom of the basal sand is not visible but flood plain borings indicate it is up to 7 m thick, the overlying alternating sand and silt section is 1-2 m thick, and the top clayey silt unit is from 1-4 m thick. Total alluvial thickness is generally <10 m. (Broughton et al., 2001).
High	Artificial fill (Holocene; man-made) over sand and silt flood plain alluvium; brown (10YR 6/2) primarily consisting of silt, sand, and chert gravel locally derived from loess, alluvium, and the Lafayette Formation. Fill occurs along roadways, reclaimed sand and gravel quarries, and as building pads. Fill thickness is generally 1 to 2 m but is 20 m ±10 m in reclaimed quarries and some bridge approaches.
Moderate	Artificial fill (Holocene; man-made) over silt flood plain alluvium, loess, or loess-covered terrace; brown (10YR 6/2) primarily consisting of silt, sand, and chert gravel locally derived from loess, alluvium, and the Lafayette Formation. Fill occurs along roadways, reclaimed sand and gravel quarries, and as building pads. Fill thickness is generally 1 to 2 m but is 20 m ±10 m in reclaimed quarries and some bridge approaches.
Moderate	Alluvium (Holocene); brown (10YR 6/2) silt with minor mixed sand and clay. Silt beds are thin to massive and the total thickness of the silt flood plains is <6 m. The dispersed sand is very fine to very coarse grained quartz and minor chert. The flood plain of Nonconnah Creek and tributaries to the Wolf River and Nonconnah Creek consist of reworked loess. Channel beds are covered with thin sand and gravel bars.
Low	Loess (late Pleistocene); brown (10YR 6/6) and light brown (10YR 7/4) silt with <10% sand and <10% clay (Spann, 1998). Regionally, the loess is dominantly quartz with minor amounts of plagioclase, orthoclase, and dolomite (Gelderloos, 1996). Borings reveal the loess is from 2-8 m thick.
Low	Loess covered terrace (Pleistocene); dense, cross-bedded, white with orange oxidation, medium-grained sand capped by loess silt (Saucier, 1987).
Low	Lafayette Formation (Upland Gravel) (Pliocene-Pleistocene); Zero to 100 feet of highly oxidized fine to coarse grained sand, chert gravel, with minor silt and clay. Variable thickness because upper and lower contacts are erosional. Colors vary from strong brown (7.5YR 4/6) to red (2.5YR 4/6). The gravel is primarily medium pebbles that are subrounded to subangular (Autin et al., 1991). Vertical cylindrical structures that appear to be root casts or burrows are locally present. The upper portion of this unit is exposed in some stream banks and in construction excavations.

Hwang et al. 1999

- ▲ Liquefy--Yes
- ○ Liquefy--No

0 2 4 Miles

0 2 4 Kilometers

N