Evansville Area Earthquake Hazards Mapping Project (EAEHMP)—Progress Report, 2008

By Oliver S. Boyd, Jennifer L. Haase, and David W. Moore

In cooperation with the Evansville Area Earthquake Hazards Mapping Project (EAEHMP)

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Abstract

Maps of surficial geology, deterministic and probabilistic seismic hazard, and liquefaction potential index have been prepared by various members of the Evansville Area Earthquake Hazard Mapping Project for seven quadrangles in the Evansville, Indiana, and Henderson, Kentucky, metropolitan areas. The surficial geologic maps feature 23 types of surficial geologic deposits, artificial fill, and undifferentiated bedrock outcrop and include alluvial and lake deposits of the Ohio River valley. Probabilistic and deterministic seismic hazard and liquefaction hazard mapping is made possible by drawing on a wealth of information including surficial geologic maps, water well logs, and in-situ testing profiles using the cone penetration test, standard penetration test, down-hole shear wave velocity tests, and seismic refraction tests. These data were compiled and collected with contributions from the Indiana Geological Survey, Kentucky Geological Survey, Illinois State Geological Survey, United States Geological Survey, and Purdue University. Hazard map products are in progress and are expected to be completed by the end of 2009, with a public roll out in early 2010. Preliminary results suggest that there is a 2 percent probability that peak ground accelerations of about 0.3 g will be exceeded in much of the study area within 50 years, which is similar to the 2002 USGS National Seismic Hazard Maps for

a firm rock site value. Accelerations as high as 0.4–0.5 g may be exceeded along the edge of the Ohio River basin. Most of the region outside of the river basin has a low liquefaction potential index (LPI), where the probability that LPI is greater than 5 (that is, there is a high potential for liquefaction) for a M7.7 New Madrid type event is only 20–30 percent. Within the river basin, most of the region has high LPI, where the probability that LPI is greater than 5 for a New Madrid type event is 80–100 percent.

Introduction

The Evansville/Henderson urban areas are currently the subject of an urban seismic-hazards investigation because of their proximity to the New Madrid seismic zone and the Wabash Valley seismic zone. The New Madrid seismic zone produced a sequence of three earthquakes with magnitude greater than 7 in 1811–1812. The Wabash Valley seismic zone produced an earthquake with a magnitude between 7 and 7.3 approximately 6100 years ago. The Evansville Area Earthquake Hazards Mapping Project (EAEHMP) is one of several urban hazard-mapping efforts funded in part by the National Earthquake Hazard Reduction Program and is being led by representatives from Purdue University; the State Geological Surveys of Kentucky, Illinois, and Indiana; the Southwest Indiana Disaster Resistant Community Corp.; the Central U.S. Earthquake Consortium (CUSEC) emergency managers; CUSEC State Geologists; and the United States Geological Survey (USGS). Other urban areas for which similar efforts were or are being done are Memphis, Tennessee; St. Louis, Missouri; Seattle, Washington; Reno, Nevada; and the Wasatch Front, Utah urban corridor.

Surficial geology and deterministic and probabilistic seismic ground-motion hazard and liquefaction hazard maps cover the Wilson, Henderson, Spottsville, West Franklin, Evansville South, and Newburgh quadrangles in Henderson County, Ky. and the Kasson, Evansville North, Daylight, West Franklin, Evansville South, Newburgh, Wilson, and Henderson quadrangles in Posey, Vanderburgh, and Warrick Counties, Ind. (fig. 1). The primary result of these products are maps of

seismic ground-motion hazards at a greater resolution and accuracy than currently available in the USGS National Seismic Hazard Maps. The greater resolution of potential ground motion hazards forecast by these maps will allow for better regional planning for the response and mitigation of future catastrophic earthquake events.

Detailed hazards mapping in the Evansville, Indiana area began about 2003. Geologists and seismologists assigned to do the work were staff of the USGS, Kentucky Geological Survey (KGS), Indiana Geological Survey (IGS), and Purdue University. Serving advisory roles were representative(s) of the Illinois State Geological Survey (ISGS), CUSEC, and civic entities in Evansville.

Following planning by a technical group, chaired by Dave Williams (KGS), geologists began field work in late 2003. Supplementing the field mapping over the next four years, 50 soundings were performed by a USGS truck-mounted cone penetrometer. Also employed was an IGS truck-mounted auger and an ISGS wire-line coring drill rig. Two seismic reflection profiles of lacustrine sediments were made, one east of Evansville and one southwest of Henderson.

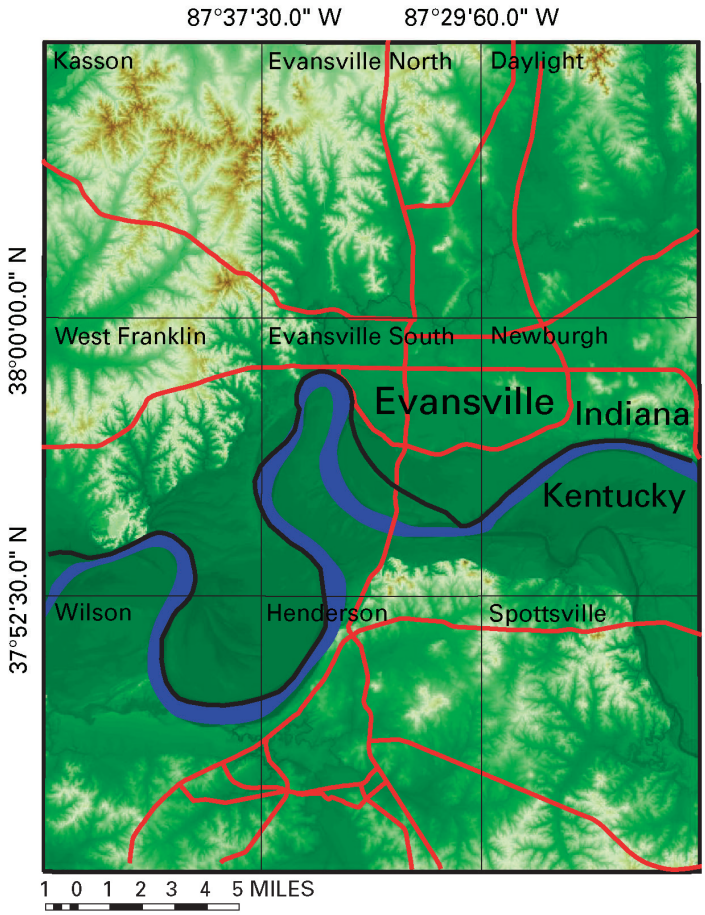

Figure 1. The Evansville area urban hazards mapping project, showing the quadrangles in Indiana and Kentucky for which seismic hazards are being calculated. Yellow areas are the urban areas of Evansville, Ind., and Henderson, Ky. Blue areas are major waterways. The basemap (green through tan) is elevation from the U.S. Geological Survey's 1-Arc Second National Elevation Dataset.

Geology

During 1960 to 1978, the USGS, in cooperation with the KGS, completed statewide detailed (1:24,000 scale) geologic mapping for Kentucky. No other state of comparable size has such comprehensive geologic mapping available. During the period from 1996 to 2004, personnel at the KGS digitized these data into GIS-compatible vector formats, which allows scalable visualization and

computer analysis of the geologic information. Since 2004, the KGS has undertaken new detailed geologic mapping of unconsolidated deposits in areas where the original USGS geologic mapping did not differentiate them in detail. This mapping has been funded by the STATEMAP component of the U.S. Geological Survey National Cooperative Geologic Mapping Program and is ongoing. The EAEHMP applies geologic mapping of unconsolidated deposits in addition to the original mapping. Subsurface data have been compiled from extensive databases of water wells, coal boreholes, oil and gas wells, and geotechnical drill logs on file at the KGS. Seismic shear-wave velocity data have been compiled from local theses and new data collection for integration into a 3D geologic model.

At present (May, 2009), a pre-peer-review draft of the geologic map for the Evansville area exists with David Moore and Ted Brandt of the Earth Surface Processes Team at the USGS Denver Geologic Discipline offices. The map depicts 23 types of surficial geologic deposits, artificial fill, and undifferentiated bedrock outcrops within the boundaries of seven 7.5-minute topographic quadrangles — Wilson, Henderson, Spottsville, West Franklin, Evansville South, Newburgh, and Evansville North — that include the Evansville and Henderson urban areas. Alluvial and lake deposits in the Ohio River valley are featured. The map is a GIS geologic database projected on a base made of two joined 1:100,000 scale topographic maps, enlarged to 1:50,000 scale. From this, color plots can be generated for technical review and later for publication as a USGS Scientific Investigations Map.

The Surficial Geologic Map of the West Franklin quadrangle, Vanderburgh and Posey Counties, Indiana and Henderson County, Kentucky (USGS Scientific Investigations Map 2967, scale 1:24,000) by Moore and others was published in 2007.

Technical reviews of the EAEHMP geologic map and text (IGS John Steinmetz and Marni Karaffa and two USGS geologists) and edits by the senior author in response are completed. Also complete is a single geodatabase with metadata in which the Kentucky and Indiana databases are kept

separate. The Ohio River shoreline is being digitized. Ted Brandt is editing the geologic mapping to ensure correct closure with the shoreline (USGS, written commun., 2008). Remaining are digital metadata review and resubmittal of entire map, text, and metadata to our Team Chief Scientist for forwarding to publication editors to await its turn for map editing. In technical review are the following: The Surficial Geology of the Wilson Quadrangle, Henderson County, Kentucky: Kentucky Geological Survey Map and Chart Series XII, 1:24,000 scale by Counts, R.C., and Martin, S.L.; The Surficial Geology of the Henderson Quadrangle, Henderson County, Kentucky: Kentucky Geological Survey Map and Chart Series XII, 1:24,000 scale by Counts, R.C., and Martin, S.L.

Seismic Ground-Motion Hazard

Deterministic and probabilistic seismic ground-motion maps are being produced as part of the EAEHMP. Purdue University is producing both map products while the Kentucky Geological Survey is producing deterministic maps. These efforts are described in more detail in the next section.

Common to these maps are two sets of critical information: bedrock depth and the shear-wave velocity of the soil column above bedrock. The data available to determine these parameters were compiled and collected through a collaboration of the EAEHMP, with contributions from the IGS, KGS, ISGS, and USGS. The existing geologic and geotechnical datasets include surficial geologic maps (described in the previous section), water-well logs, and in-situ testing profiles using the cone penetrometer test (CPT), standard penetration test (SPT), down-hole shear-wave velocity tests, and seismic refraction tests.

48 seismic cone penetrometer test (SCPT) observations were made on the Indiana side of the Ohio River (T. Holzer, USGS, written commun., 2003). These SCPT measurements contain tip resistance for soil, sleeve friction between testing-device cone and soil, and S-wave velocity. Soil type is inferred from these measurements. Soil description logs at over 60 geotechnical boring sites and 570

SPT blow count profiles were compiled by the IGS (Choi and Hill, unpublished data, contact jhaase@purdue.edu). The SPT blow count data were used to estimate shear wave velocity from empirical correlation equations. Thirty-three borehole S-wave velocity profiles from down-hole tests and soil type logs were also compiled (Eggert and others, 1994). In addition, the IGS database of over 230 seismic P-wave refraction profiles (Rudman and others, 1973) and 15 S-wave refraction profiles (Bauer, 2004) are available in and around Evansville. These P-wave and S-wave refraction profiles were used to estimate the soil thickness and provide the seismic shear wave velocities in the soil and rock. The IGS iLITH GIS database of approximately 900 water-well logs provided additional data on the soil thickness above bedrock and on the soil-type profile with depth (Bleuer, 2000). Bedrock elevations from KGS oil, gas, and water-well logs (Ron Counts, written commun., 2005) are available on the Kentucky side of the Ohio River as well. The locations of all the data used in the process of developing a proxy velocity model are illustrated in figure 2. The near final map of bedrock depth is presented in figure 3. Depths vary from 0 meters in the uplands to 55 meters in the Ohio River channel.

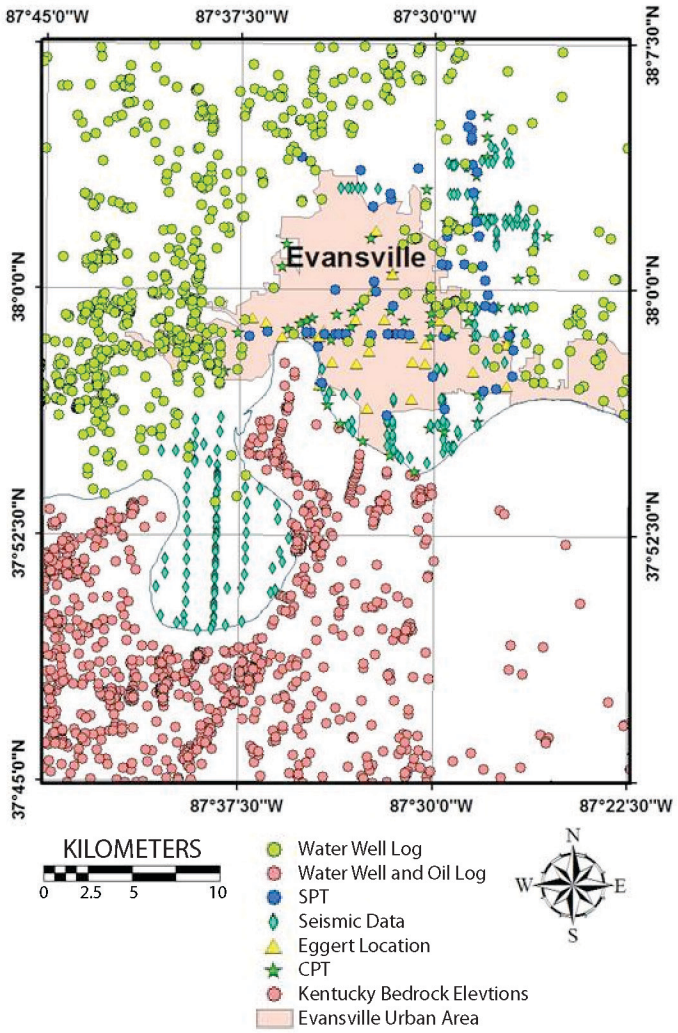

Figure 2. The Evansville area, including the locations of wells and borings used to derive the bedrock depth map.

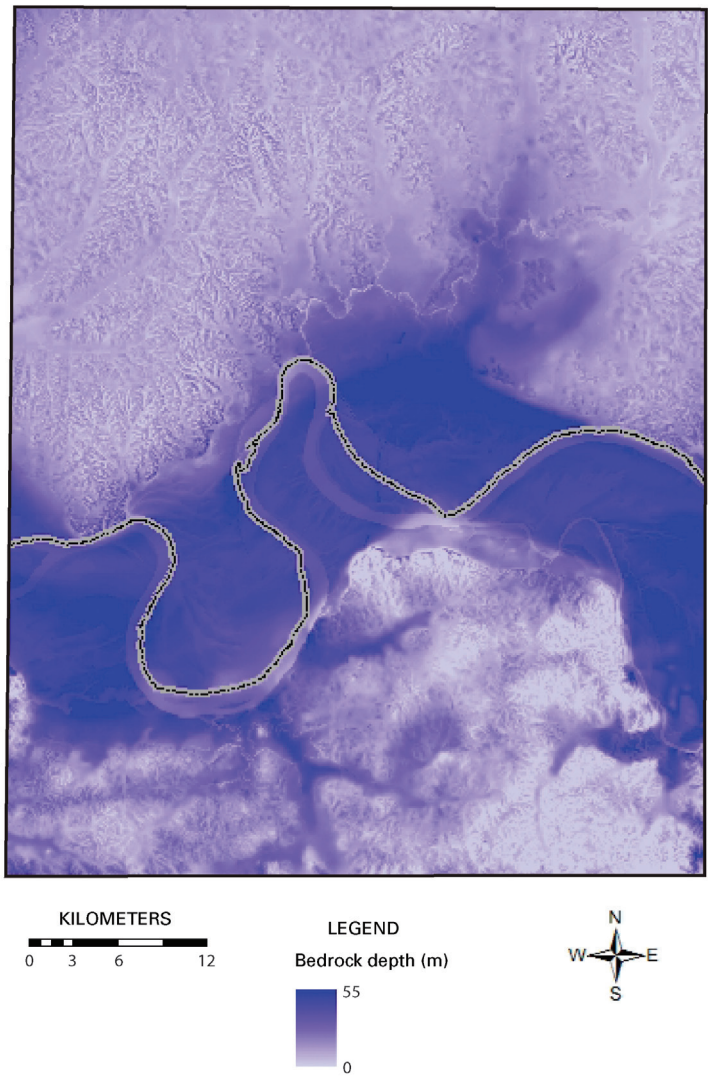

Figure 3. Preliminary map of bedrock depth in feet, which will be used in probabilistic and deterministic ground-motion simulations.

Deterministic maps

Deterministic seismic-hazard maps are being produced by Purdue University for the nine quadrangle regions of the Evansville area. Purdue will use the suite of ground-motion relationships that were used in the 2008 USGS National Seismic Hazard Maps (Petersen and others, 2008). They will generate hazard maps for the earthquake scenarios listed in table 1 and shown in figure 4. Additional

scenarios, as depicted in figure 4, may be performed to assess the variability in the resulting ground motions. Ground motions calculated from the ground-motion relationships will be modified using information about soil profile seismic velocity and bedrock depth, and using the amplification program, SHAKE 91 (Idriss and Sun, 1992), with time series from 10 large magnitude earthquakes. Preliminary results appear in figure 5 and indicate that ground-motion amplification is frequency dependent.

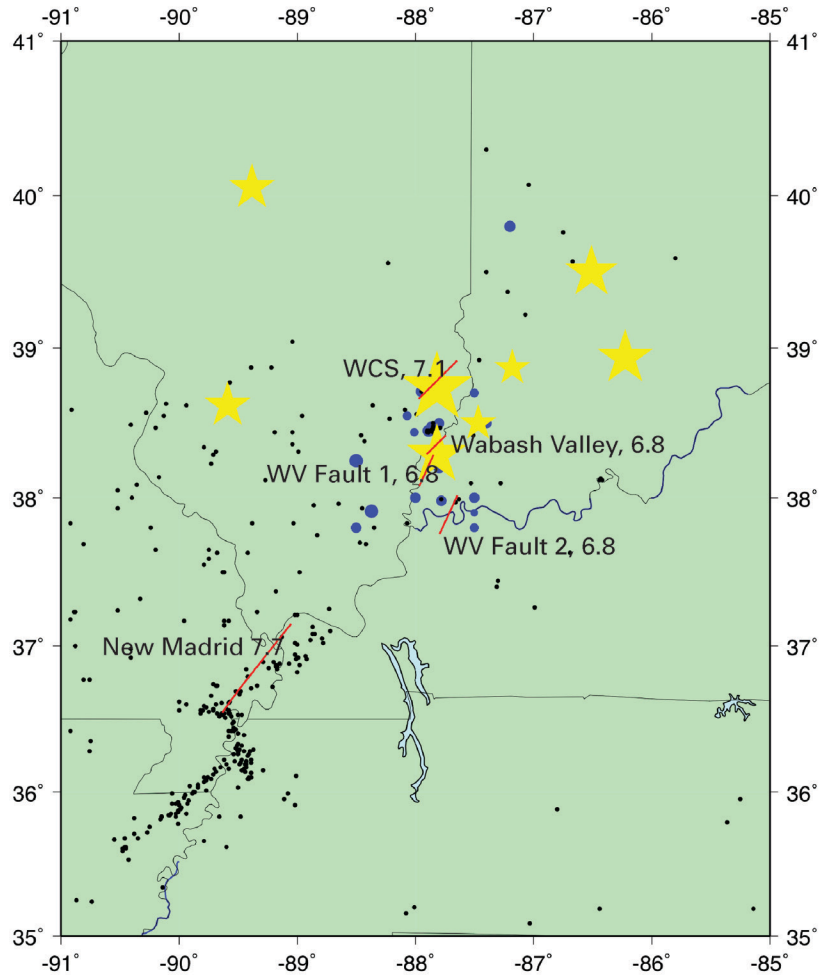

Figure 4. Scenario earthquakes used in deterministic study (red lines). Yellow stars are the locations of paleoearthquakes greater than M6.0 (Wheeler and Cramer, 2002), and black dots are the locations of earthquakes scaled by magnitude.

Probabilistic maps

Purdue University has completed a draft probabilistic seismic-hazard map for the nine quadrangle region of the Evansville area at a spatial resolution of 1 km. It is based on the seismic sources and ground-motion relationships in the 2002 USGS National Seismic Hazard Maps (Frankel and others, 2002) but accounts for site amplification derived from estimates and measurements of bedrock depth and soil velocity in the study area. Purdue is currently working on incorporating the sources and ground-motion relationships from the 2008 USGS National Seismic Hazard Maps (Petersen and others, 2008).

Preliminary results based on the 2002 USGS National maps suggest that there is a 2 percent probability that peak ground accelerations of about 0.3 g will be exceeded in much of the study area within 50 years. These values are very similar to the 2002 USGS National Seismic Hazard Maps (Frankel and others, 2002). Accelerations as high as 0.4–0.5 g may be exceeded along the edge of the Ohio River basin.

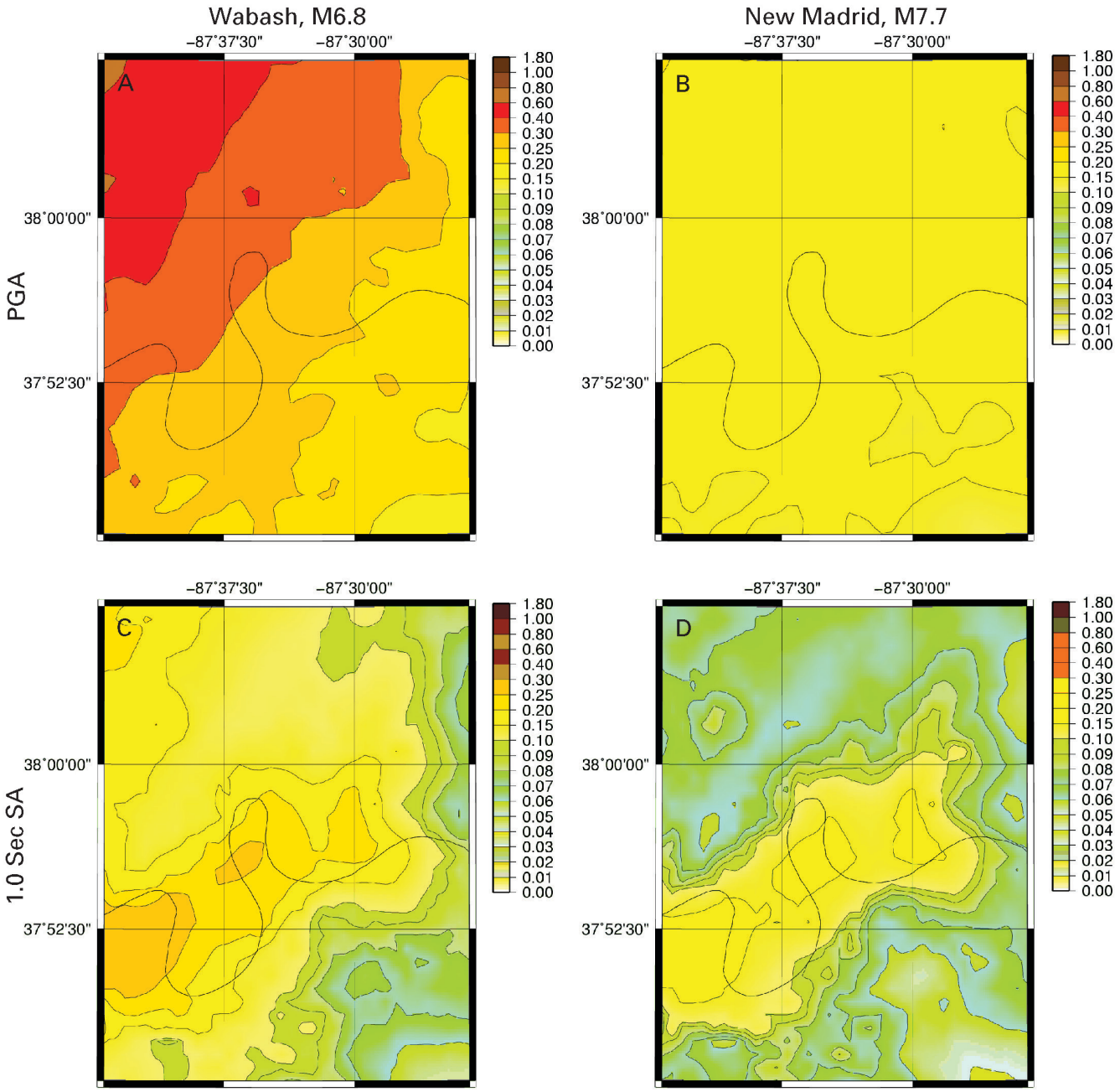

Figure 5. Preliminary results in Evansville of deterministic peak ground accelerations (A and B) and 1 second spectral accelerations (C and D) for magnitude 6.8 (A and C) and 7.7 (B and D) events in the Wabash and New Madrid seismic zones, respectively.

Table 1. Scenario earthquakes proposed for the Evansville hazard mapping project.

Scenario	Source Zone	Magnitude	Recurrence interval	Distance to Evans.
2	WV Fault 1	M6.8	2,000 to 4,000 years	40 km
3	New Madrid	M7.7	500 to 750 years	200 km

Liquefaction Hazard mapping

Evansville, Indiana, located on the banks of the Ohio River, is susceptible to liquefaction-induced damage in the event of significant earthquake ground motions. Purdue University is calculating the liquefaction potential index for the Evansville area, as a complement to recent work on deterministic and probabilistic seismic hazard analyses (Haase and others, 2006). There is a 2 percent probability that peak ground accelerations of 0.3 g will be exceeded in much of the study area within 50 years. Accelerations as high as 0.4–0.5 g may be exceeded along the river basin edges. These acceleration levels are important to consider in the study of liquefaction for the Evansville area.

Recently acquired cone penetrometer test data are used to estimate the factor of safety against liquefaction at 58 sites in the study region. The unconsolidated sediments within the study region are grouped into three subgroups based on common material properties. The liquefaction potential index (LPI) is calculated to map the spatial variability of liquefaction hazard. Since there are high uncertainties in the characterization of the soil column due to horizontal spatial variability, a probabilistic method is adopted for the hazard mapping. It is based on the statistical characteristics of the material properties within each subgroup. The resulting maps for scenario earthquakes of magnitude 6.8 and 7.7 show the mean LPI, and the probability that the LPI is greater than threshold values of 5 (that is, there is a high potential for liquefaction) and 15 (that is, there is a very high potential for liquefaction). The LPI is high in the river alluvium subgroup, where the soil profiles contain predominantly sand. The probability that LPI is greater than 5 for a New Madrid type event in this

subgroup is 80–100 percent. The maps also show a contrasting region of lacustrine deposits that predominantly include clayey soil with a lower liquefaction hazard. The probability that LPI is greater than 5 for a New Madrid type event in this subgroup is only 20–30 percent. The soil profiles within the deposits of terrace alluvium deposits are more complex as they contain highly variable sequences of silty sand, clayey sand, and sandy clay. Because there is less consistency of the liquefaction potential index within this subgroup, a probabilistic approach is more appropriate for liquefaction hazard mapping. Liquefaction potential for a Wabash event is currently being calculated. These maps are expected to be complete by late 2009. A timeline for the completion of products appears in table 2.

Table 2. 2009 Timeline for EAEHMP products.

Product	May	June	July	August	…	Nov.
Geologic Map						
Documentation						
Deterministic maps						
Documentation						
Probabilistic maps						
Documentation						
Liquefaction maps						
Documentation						
Public roll out						Early 2010

References

Bauer, R.A., 2004, Central U.S. shear wave velocity database with accompanying geological/geotechnical information of nonlithified geologic materials: NEHRP Final Technical report, 04HQGR0074, 29 p.

Bleuer, N.K., 2000, iLith Database of the Indiana Geological Survey: IGS Open-File Study 00–8, on CD–ROM, Indiana Geological Survey, Bloomington, Ind.

Eggert, D.L., Samuelson, A.C., Bray, J.D., Chang, C.W., Eckhoff, W.R., Kayabali, K., McClees, E.J., West, T.R., Woodfield, M.C., and Zheng, B., 1994, Final Report to the City of Evansville—Shear-wave and earthquake hazard mapping of Evansville, Indiana: IGS Open-File Study 94–19, Indiana Geological Survey, Bloomington, Ind., 17 p.

Frankel, A.D, Petersen M.D., Mueller C.S., Haller K.M., Wheeler R.L., Leyendecker E.V., Wesson R.L., Harmsen S.C., Cramer C.H., Perkins D.M., and Rukstales K.S., 2002, Documentation for the 2002 update of the National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2002–420, 33 p.

Haase, J.S., Nowack, R.L. and Choi, Y.S., 2006, Probabilistic seismic hazard assessment including site effects for Evansville, Indiana, and the surrounding region: NEHRP Final Technical Report 05HQGR0033, Purdue University, West Lafayette, Ind.

Idriss, I.M., and Sun, J.I., 1992, User's manual for SHAKE91: Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, Calif.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Y., Boyd, O.S., Perkins, D.M., Luco, N., Field, E.H., Wills, C.J., and Rukstales, K.S., 2008, Documentation for the 2008 update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report, 2008–1128, 61 p.

Rudman, A.J., Biggs, M.E., Blakely, R.F., and Whaley, J.F., 1973, Statistical studies of Indiana bedrock velocities: Mapping applications, Indiana Academy of Science, v. 83, p. 284–290.

Somerville, P., Collins, N., Abrahamson, N., Graves, R., and Saikia, C., 2001, Ground motion attenuation relations for the central and eastern United States: Final report to U.S. Geological Survey, 16 p.

Wheeler, R.L. and Cramer, C.H., 2002, Updated seismic hazard in the southern Illinois Basin—geological and geophysical foundations for use in the 2002 USGS National Seismic-hazard maps: Seismological Research Letters, v. 73, n. 5, p. 776–791.