Final Technical Report

Shear Wave Velocity, Geology and Geotechnical Data of Earth Materials in the Central U.S. Urban Hazard Mapping Areas

External Grant Award Number 05-HQ-GR-0056

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Abstract

This project collects shear wave velocity measurements of nonlithified geologic materials, lithologic descriptions and geotechnical properties for the cooperative earthquake hazard mapping in the St. Louis Urban Hazard Mapping and the Tri-State (Evansville) Urban Hazard Mapping area of Indiana, Kentucky and Illinois. This will ultimately produce a region-specific relationship between lithologies and seismic wave velocities for use in production of soil profile type derivative maps. This is being performed by collecting existing shear wave velocity, coordinating with USGS Golden office on their measuring of situ shear wave velocities in materials and areas where no or few values exist, and collecting lithologic and geotechnical data at new shear wave velocity sites. These data are being entered into electronic databases. Also some comparison of shear wave velocity measuring techniques and their variations in estimating the soil profile type is performed.

Introduction

This project has the Illinois, Indiana, Kentucky and Missouri Geological Surveys collecting shear wave velocity measurements of nonlithified geologic materials, lithologic descriptions and geotechnical properties for the cooperative earthquake hazard mapping in the St. Louis Urban Hazard Mapping and the Tri-State (Evansville) Urban Hazard Mapping area of Indiana, Kentucky and Illinois. This work is being performed in cooperation of the two working groups in each region including the U.S. Geological Survey who has liaisons in each group and who is mapping surficial materials in the Evansville area. The work of the State Surveys will ultimately produce a region-specific relationship between lithologies and seismic wave velocities for use in production of soil profile type derivative maps. This is being performed by collecting existing shear wave velocity, coordinating with USGS Golden office on their measuring of situ shear wave velocities in materials and areas where no or few values exist, and collecting lithologic and geotechnical data at new shear wave velocity sites. These data are being entered into electronic databases. Also some comparison of shear wave velocity measuring techniques and their variations in estimating the soil profile type is performed. A report on each state survey's work is described below.

Investigations undertaken

COSMOS Database

A distributed database was proposed for the Urban Hazard Mapping areas of the greater St. Louis, Missouri and Evansville, Indiana areas. The CUSEC State Geologists attended a workshop in Memphis, Tennessee on the Consortium of Strong Motion Observations Stations (COSMOS) geotechnical virtual database. This workshop was sponsored by the U.S. Geological Survey as a more detailed introduction to this distributed database structure. This distributed database has been assembled in Southern California with various California participants to present their available data through one portal site. Instructors for the workshop were from University of Southern California, California Department of Transportation and the U.S. Geological Survey - Menlo Park. The workshop presented the details on the system and present up coming changes through the adoption of the system by international communities.

The individual geological surveys reviewed the amount of additional, new work that needs to be performed to make our databases compatible with the Cosmos/Digs database and reviewed the needs for such a database to complete the urban hazard mapping projects in the two urban areas. Through discussions with the USGS leaders of both mapping areas, it was decided that the extra work to make databases compatible with COSMOS was not needed to perform the work in both areas. Also it was felt that redirecting our work to the implementation of a new distributed database would delay making data available for analysis.

Indiana Geological Survey

During this grant period, the Indiana Geological Survey provided partial support for a student, from Purdue University, to enter geotechnical data from earlier work in the Evansville, Indiana area. The geotechnical borehole information was collected throughout the city and county when downhole shear wave velocity measurements were performed. The data was entered using the gINT commercial software which allows the data to be translated into a Microsoft Excel Workbook. Sixty-one project sites had some information entered from 368 borehole logs.

The Indiana Geological Survey (IGS) has continued its study of the Quaternary stratigraphy of the Bluegrass Creek and Pigeon Creek drainage basins as part of a seismic risk investigation in the greater Evansville area, Indiana. The goal of this project is to generate the information essential to adequately define the three-dimensional distribution and thickness of seismically sensitive sediments such as wet sands and thick, soft clays. Such information is essential to evaluate tributary valley-fill models, and to provide the data needed to map lithologies and associated liquefaction and shaking susceptibilities here and in similar tributary basins of the Ohio, Wabash, and Mississippi rivers

An important source of data was added in 2005 with the acquisition of a core (06-1001) and an associated gamma ray log for a location on the north side of Evansville (Figs. 1 and 2). The core was funded by the U.S. Geological Survey (USGS) and drilled and logged by the Illinois State Geological Survey (ISGS). This data, in combination with a core hole drilled in 2004, north of Pigeon Creek (04-1095) (Figs. 1 and 2) and the approximately 4.5-miles of seismic lines acquired in 2004 in three segments, County Line Road north of Pigeon Creek, Burkhardt Road south of Pigeon Creek, and Kimber Lane north of Highway 66 plus pre-existing IGS gamma-ray logs and cuttings descriptions have resulted in the establishment of a detailed Quaternary stratigraphy for the greater Evansville area.

The IGS efforts this past year have been in compiling and correlating, within the study area, dozens of gamma-ray logs and drill cuttings currently archived in the IGS files. In addition, the two core descriptions and seismic data recently obtained for this study have been tied into this data base. From this data base, 7 lines of cross section have been constructed (Fig. 2) to facilitate facies reconstructions and to resolve depositional sequences.

Two samples have been sent to the ISGS for radiocarbon age determination. The samples where selected to help define the age of the stratigraphic units discussed below.

Our studies have established that the valley-fill materials for the incised tributary valleys in the greater Evansville area can be broken down into five intervals. In ascending order they are: 1) a lower pedogenically modified interval that rests directly on the basal Quaternary/Pennsylvanian unconformity and that is composed of a variety of lithologies ranging from coarse-grained sands to muds; 2) a fluvial deltaic/marginal lacustrine/lacustrine facies of mostly silt and clays with interfingering fine-grained sands

derived primarily from Pennsylvanian bedrock; 3) an intermediate fluvial/floodplain succession with well developed paleosols with an intervening lacustrine/marginal lacustrine facies formed in mostly fine-grained facies; 4) an upper fluvial deltaic/marginal lacustrine/lacustrine facies composed mostly of silt and clay with interfingering very fine-grained sands and coarse silts primarily derived from reworked loess; and 5) an upper loess and pedogenic facies composed of silt and clay formed under largely subaerial conditions. Units 3 and 4 have been sampled for radiocarbon age determination.

The five intervals are best defined within the paleovalley tributaries to the ancestral Ohio River. The facies tend to become sandier towards the Ohio River (Fig. 3). The Ohio River paleovalley fills are principally composed of sands and some gravels representing stacked channels of the Quaternary Ohio River. Finer-grained facies near the base of the Ohio River paleovalley fills (Fig. 3) imply a possible change in fluvial styles from high-sinuosity (meandering?) near the base to mud-poor, sand-dominated braided channel-fill in the intermediate and upper portions.

The IGS is currently awaiting permission from Vanderburgh County to use the INDOT Geoprobe to acquire additional samples for age dating. It is hoped that funding for OSL and additional radiocarbon dating can be obtained to further define the age of the 5 stratigraphic units mentioned above.

We also intend to correlate the IGS data to the USGS cone penetrometer data and ultimately to the shear wave data generated by the USGS.

We are currently evaluating depositional models and comparing our data to Kentucky Geological Survey data obtained by Ron Counts and William Andrews for the Ohio River valley.

Missouri Geological Survey

The Missouri Geological Survey continued compiling existing geotechnical boring data for use in the St. Louis Area Earthquake Hazard Mapping Project. In the past year an additional 219 borings logs were entered into a Microsoft Access database for use in mapping potential earthquake seismic liquefaction and amplification hazards in the St. Louis, Missouri area. The total number of borings entered for the past two years are 374 (see Figure 4).

The data entered include a variety of field and laboratory geotechnical attributes such as water levels, SPT blow counts, liquid limits-plasticity index, and material descriptions. Figures 5 through 8 are summary maps of boring locations and associated data. All logs and associated map or table information in the reports will also be preserved in Acrobat *.pdf file format.

These boring records compliment the current Missouri Geological Survey effort to obtain and compile data from the St. Louis Metropolitan Sewer District, the Missouri

Department of Transportation and the US Army Corp of Engineers. Both data sets will be compiled into the same series of database tables, and in addition to being used to map earthquake hazards will be made available for public use.

Kentucky Geological Survey

The University of Kentucky researchers have been acquiring seismic refraction/reflection and downhole data for characterizing the shear-wave velocity models of the soil/sediment overburden in the central United States for more than a decade. The dataset includes densely spaced measurements for urban hazard mapping (microzonation) studies and coarsely spaced measurements for regional assessments; however, the 500+ measurements and their derivative products often do not exist in an organized electronic form, limiting its accessibility for use by other researchers (Figure 9). In order to make these data more accessible, a database has been constructed using the ArcGIS 9.1 software. The data will exist in a format that can later be integrated into a regional or national database that serves a wide array of users. The shear-wave velocities collected at locations throughout the upper Mississippi embayment and lower Wabash Valley, as well as the adjacent regions are archived with corresponding x, y, and z- coordinate information, impedance boundary elevations, available geotechnical index properties, as well as the velocities. The database design includes flexibility to also allow comprehensive Kentucky Seismic and Strong Motion Network data input (e.g., recorded ground motion values/time histories, weak motion waveform data, etc.) from nearby stations.

Significant progress has been made on this project. The database has been created and all data have been entered. The derivative maps have been completed and a MS thesis is near completed. The metadata and other documentation contained within the database in ArcCatalog continue to be updated.

Illinois State Geological Survey

The Survey has coordinated with the University of Missouri – Rolla staff in assisting to pick locations in Illinois for their MASW shear wave velocity measurements. Some of their measurement sites are also sites where the ISGS has performed downhole shear wave velocity measurements within cased boreholes. This has allowed comparison between these two techniques at the same site (Figure 10 & 11). This site is in the America Bottom in the St. Louis Urban Hazard Mapping area where there is about 100 feet of sand with some gravel resting over the Mississippian limestone. The ISGS has coordinated with the U.S. Geological Survey's Earth Hazard Program staff to have their shear wave measurement techniques performed at the same site. This will allow for a comparison between 3 different shear wave velocity measurement techniques at a fairly simple geologic site. The comparison between the downhole and MASW methods show up to a 35% difference in values (Figure 11). Also the two measuring/analysis techniques can produce a different amplification values as calculated by Shake91 (Figure 12). Differences in assigning the NEHRP soil profile type are also shown by using the

soil column shear wave velocity average or by amplification values based on Shake91 (Table 1). The average shear wave velocities calculated for the various measuring techniques shows about a 15% difference.

The Illinois State Geological Survey (ISGS) has gathered many more geotechnical borehole descriptions along the Mississippi River from the Illinois Department of Transportation (IDOT) in the St. Louis Urban Hazard Mapping area. The data is being placed into an Engineering Geology Database. Illinois focused on producing a geotechnical borehole database which was capable of storing all the typical information found on IDOT borehole records. This project focused on the new Mississippi River Bridge, approaches and highway changes proposed for areas in Madison County and St. Clair Counties. Twenty-nine volumes of geotechnical reports have been obtained by the ISGS containing a total of 750 soil boring logs for this region. These boring logs include valuable information concerning the geology of this area, including detailed lithologic descriptions, depth to bedrock, moisture content, compressive strength and blow counts.

The information contained in these reports is being converted into the electronic databases using Microsoft Access and Oracle. They will incorporate all new data as well as the existing ISGS data that is already in the Oracle database for this area.

We used Microsoft Access to create a database containing all 750 boreholes. The information contained in this database so far is:

- Boring Name
- Report No.
- Station/Offset
- Boring Depth
- Latitude/Longitude
- Northing/Easting (UTM)

The Station/Offset and Boring Depth information came directly from the geotechnical reports received. The Latitude/Longitude and Northing/Easting information came from separate spreadsheets. Coordinate conversions in this database will be made through the use of the Army Corps of Engineers' software program, Corpscon.

Right now a limited set of geotechnical properties is available on the Survey's Oracle database. All borehole soil descriptions outside of the new 750 boreholes described above are within the Oracle database for the St. Louis Urban Hazard Mapping Project. These boreholes include oil & gas, coal exploration, and some geotechnical boreholes.

Coordination with USGS

The Central U.S. Earthquake Consortium State Geologists has coordinated with the Earth Hazards Program in selection of some sites for shear wave velocity measurements. This allows a comparison of 3 different measuring techniques at the same location.

Summary

The Central U.S. Earthquake Consortium (CUSEC) State Geologists are gathering geological information in order that a geologic map of the materials resting on the bedrock at a scale of 1:24,000 or 1 inch = 2,000 feet can be produced in the cooperative earthquake hazard mapping areas of St. Louis Urban Hazard Mapping and the Tri-State (Evansville) Urban Hazard Mapping area of Indiana, Kentucky and Illinois. The geologic map, along with measurements of the soil's properties, will be used to classify the various soils as to how much they will amplify earthquake ground motions. The amplification maps can be used in the Federal Emergency Management Agency's earthquake loss estimation program (HAZUS) to better estimate the amount of damages a community may expect from various earthquakes. This work entails gathering all existing borehole information for stratigraphy and measuring shear wave velocity leading to the production of new maps of the "soils" and their thickness. The average shear wave velocity is calculated for the total column of "soil" and used to produce a map classifying the soils as to how much they will amplify earthquake ground motions.

Much of the geotechnical and shear wave velocity data are available in paper copy. Data is being added to electronic databases and we are working with USGS to form a consensus on the fields of a database for the two urban hazard mapping areas.

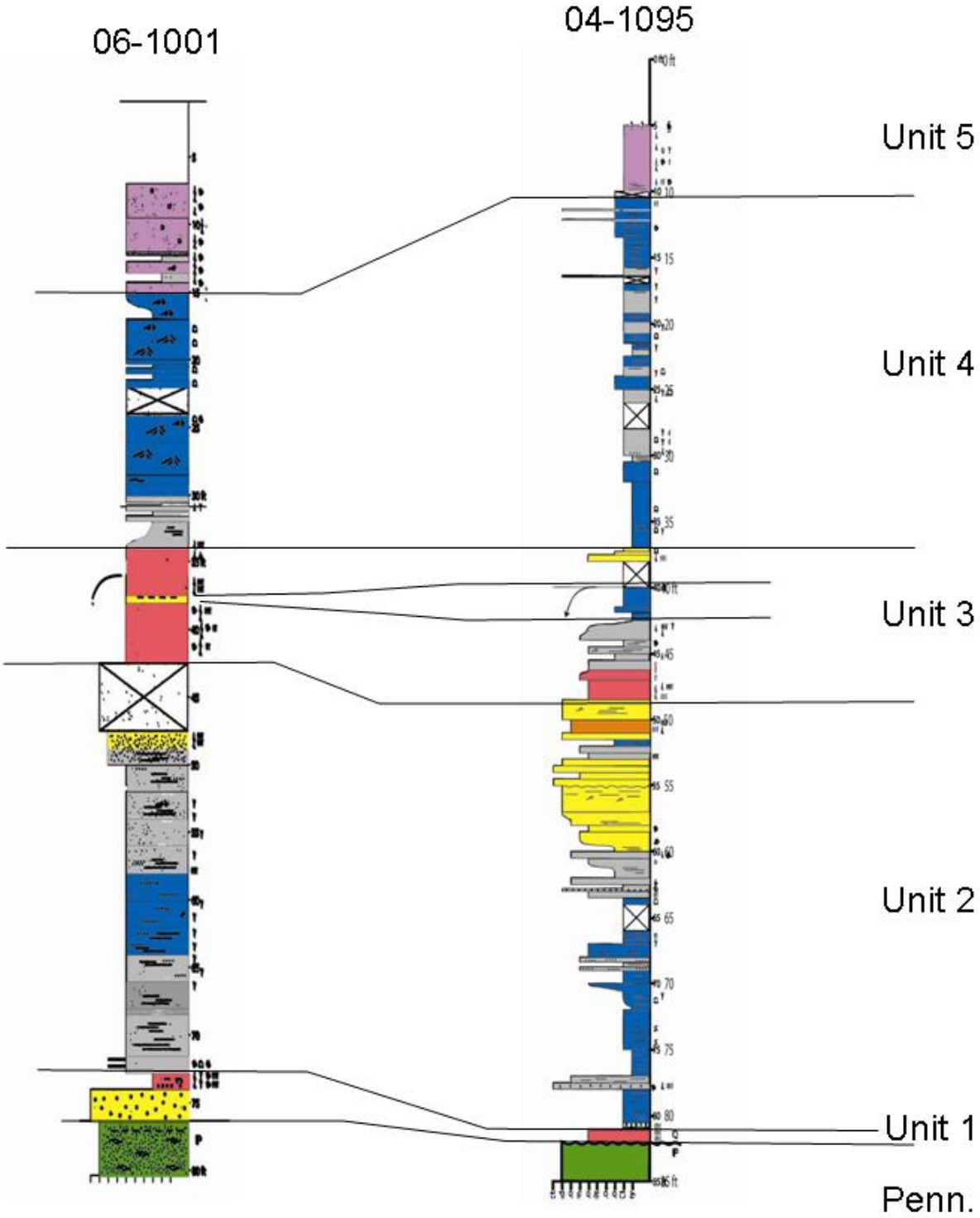


Figure 1. Graphic logs of two core holes from Evansville study area. Yellow – fluvial, fluvial/deltaic deposits; grey – marginal lacustrine; blue – lacustrine; red – pedogenically modified floodplain; purple – loess deposits; green – Pennsylvanian bedrock.

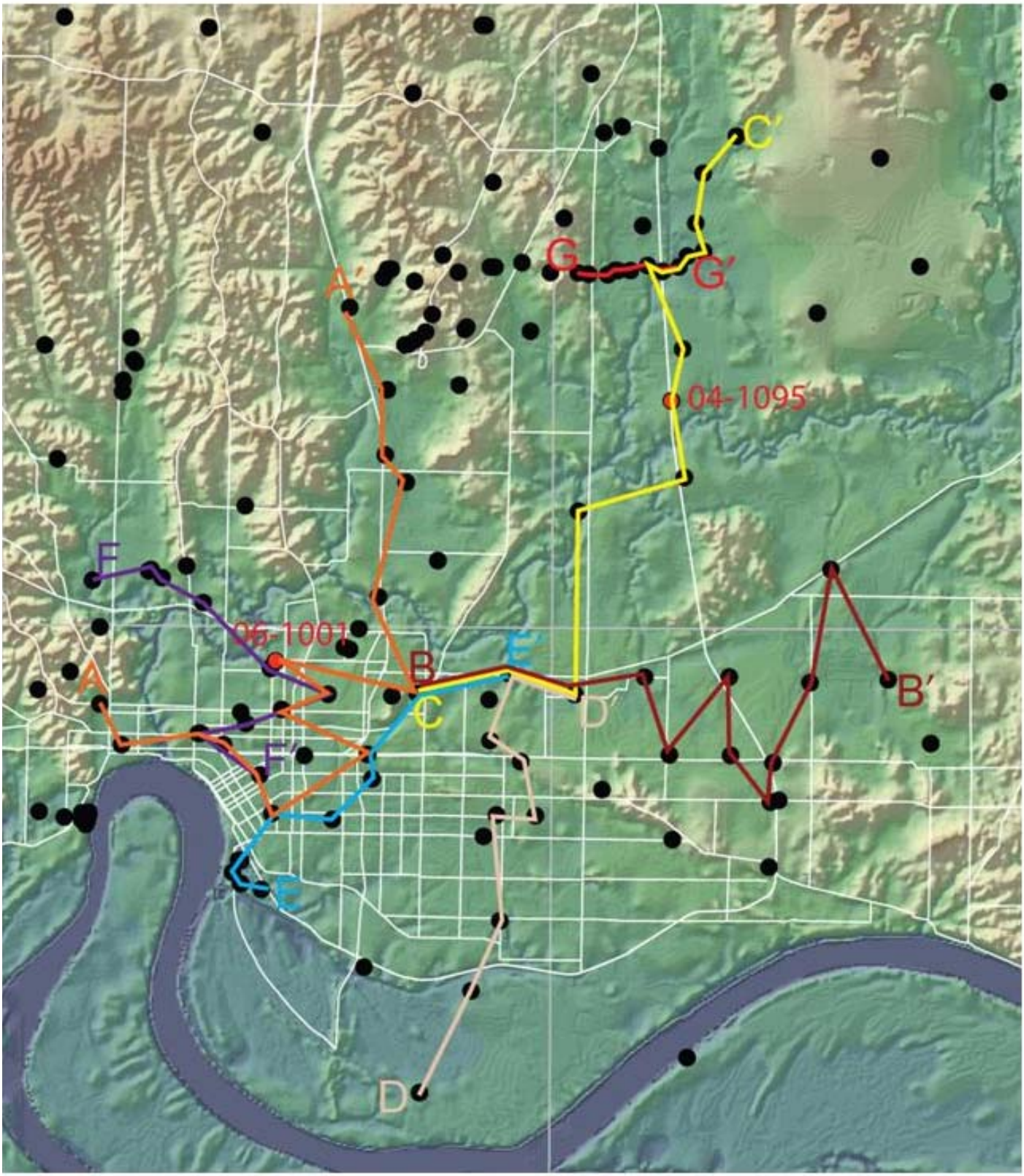


Figure 2. Map showing location of IGS gamma-ray logs used for this study (black dots) and core hole locations (red dots) and lines of cross sections constructed for this study.

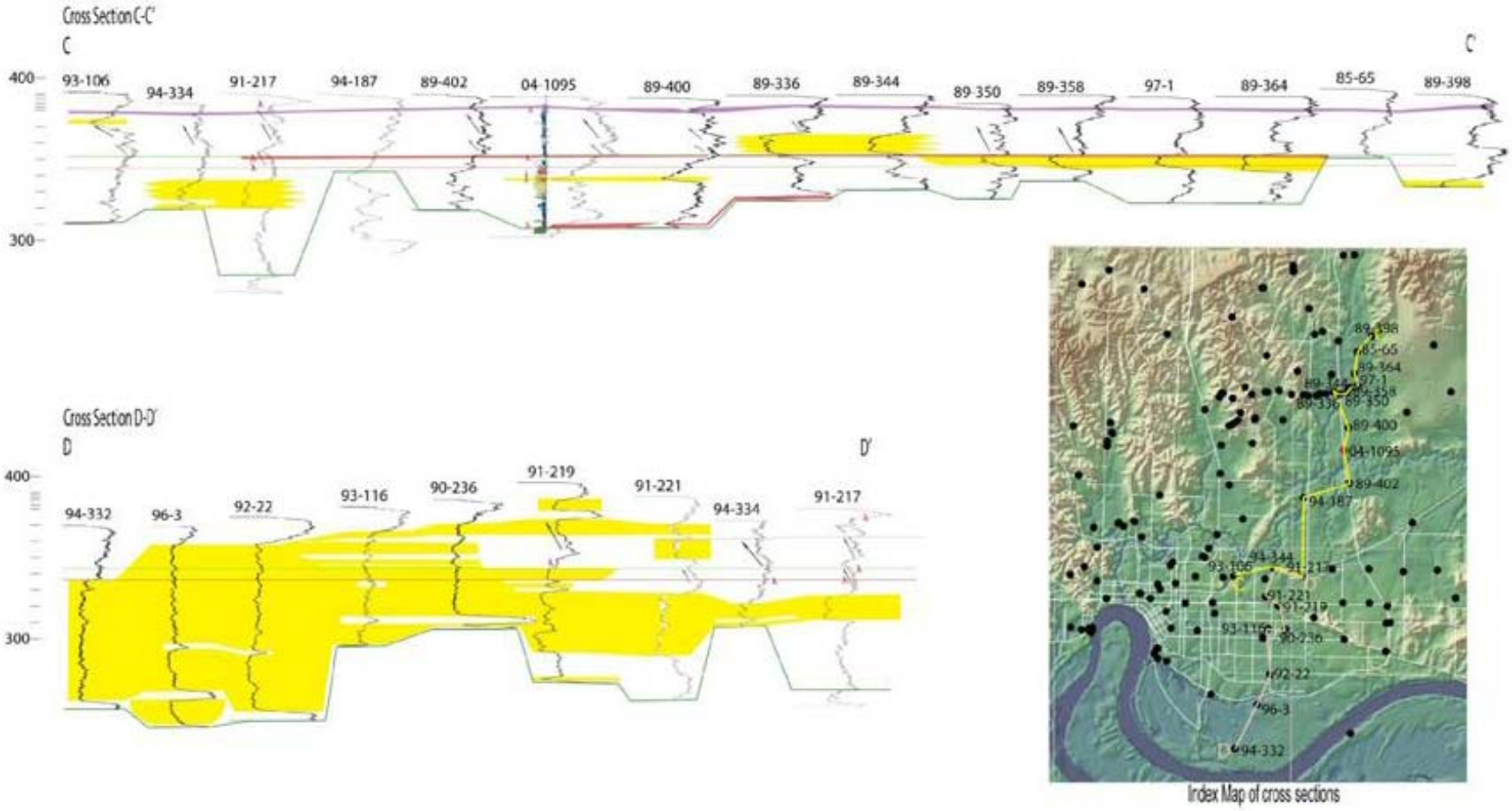
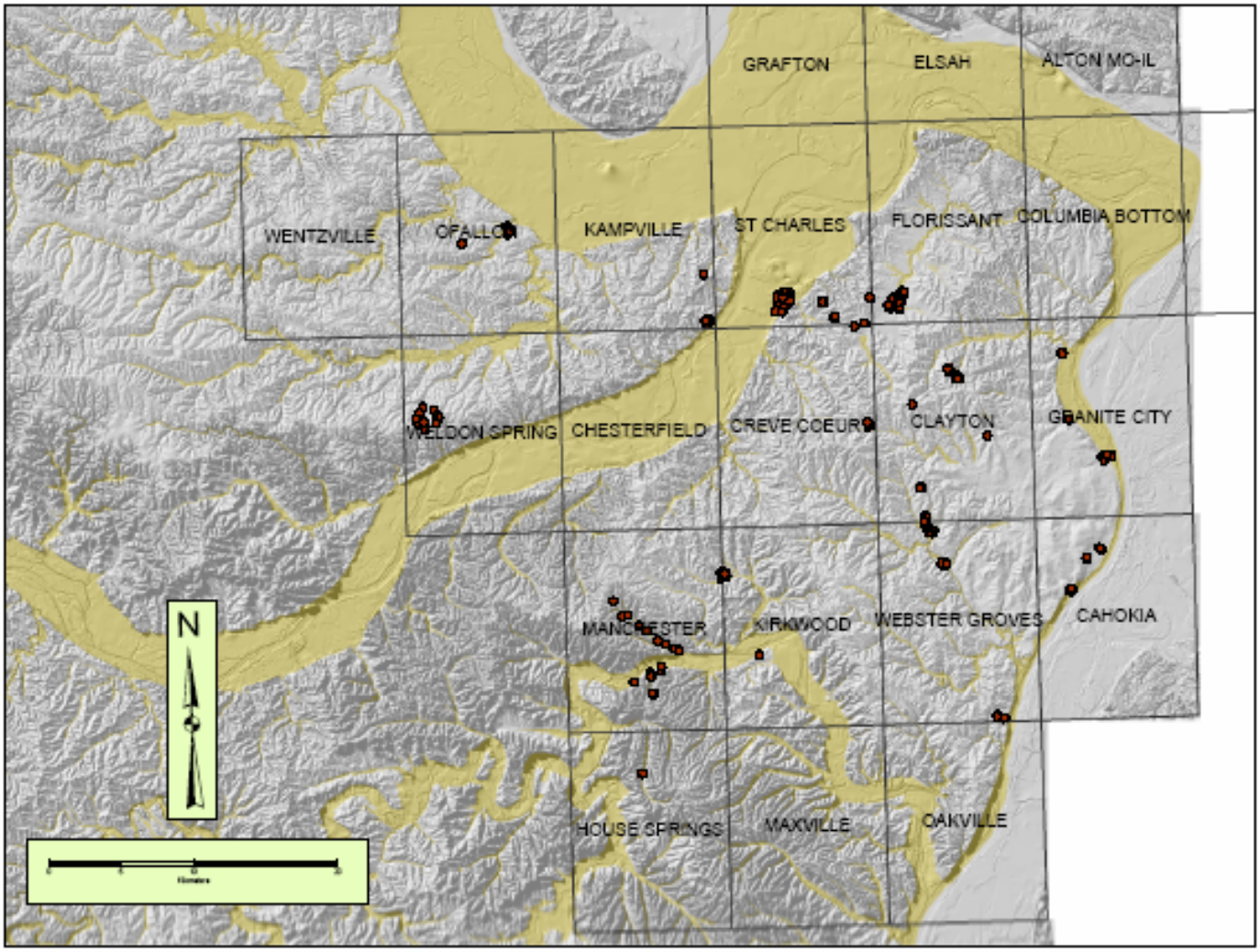


Figure3 . Two lines of cross section showing distribution of sand (yellow) up the Bluegrass Creek drainage from the Ohio River.



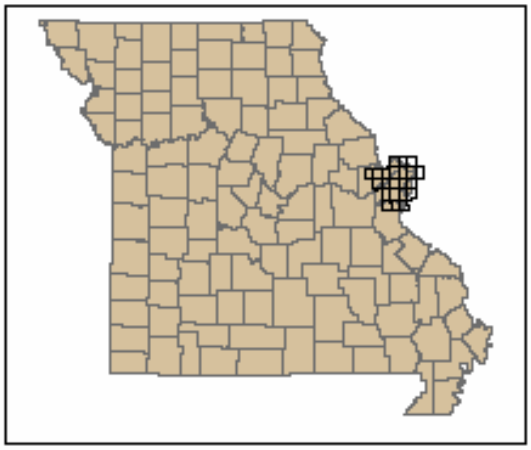


Figure 4. Missouri Geological Survey Surficial Material and Geotechnical Database, St. Louis, Missouri Area. During the two-year period a total of 374 borings have been entered for the area of the St. Louis Area Earthquake Hazard Mapping Project. The boring data include materials descriptions, physical properties and depth to groundwater.

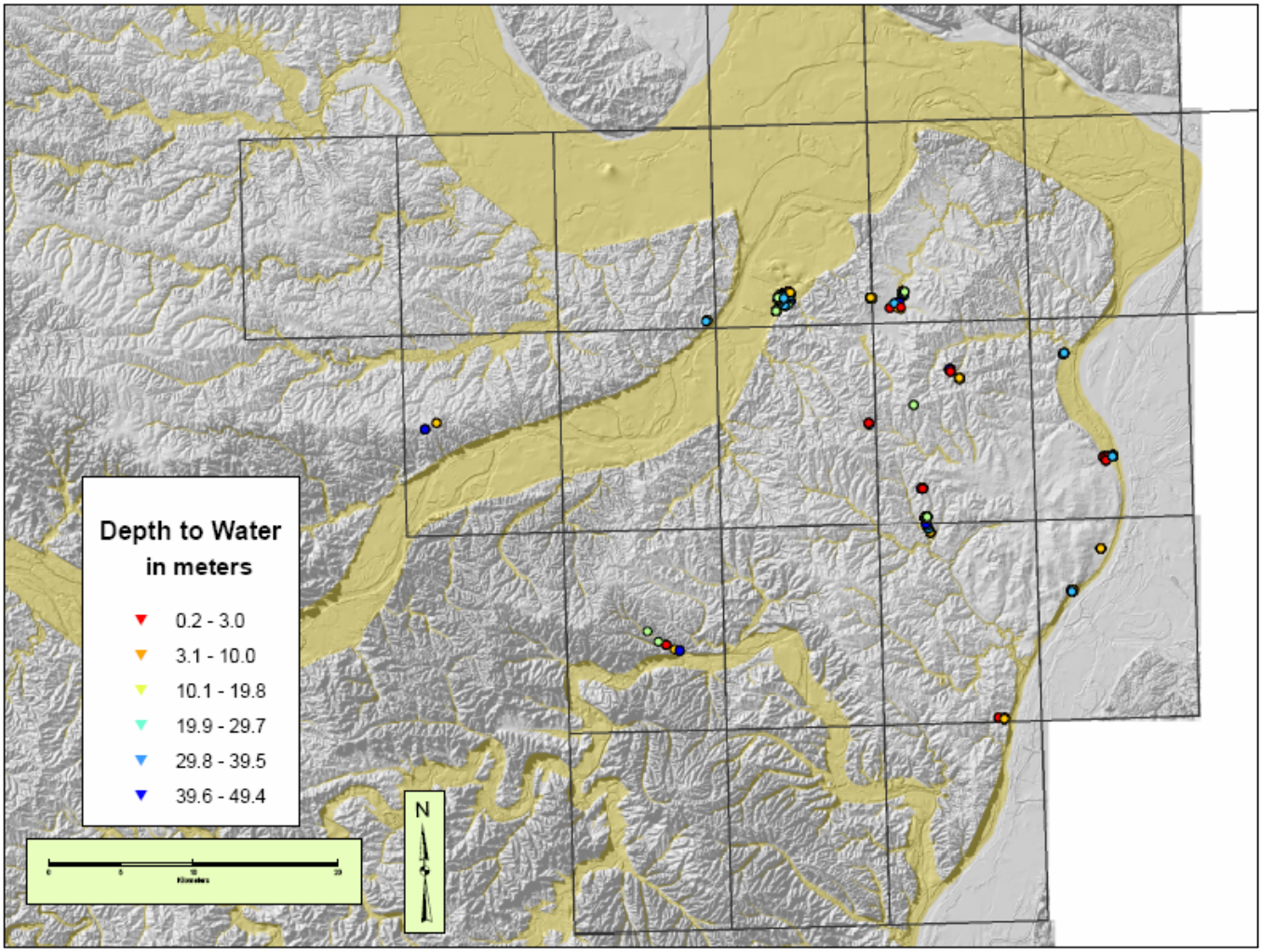


Figure 5. Depth to Groundwater in Meters. 181 borings had depth to water level data.

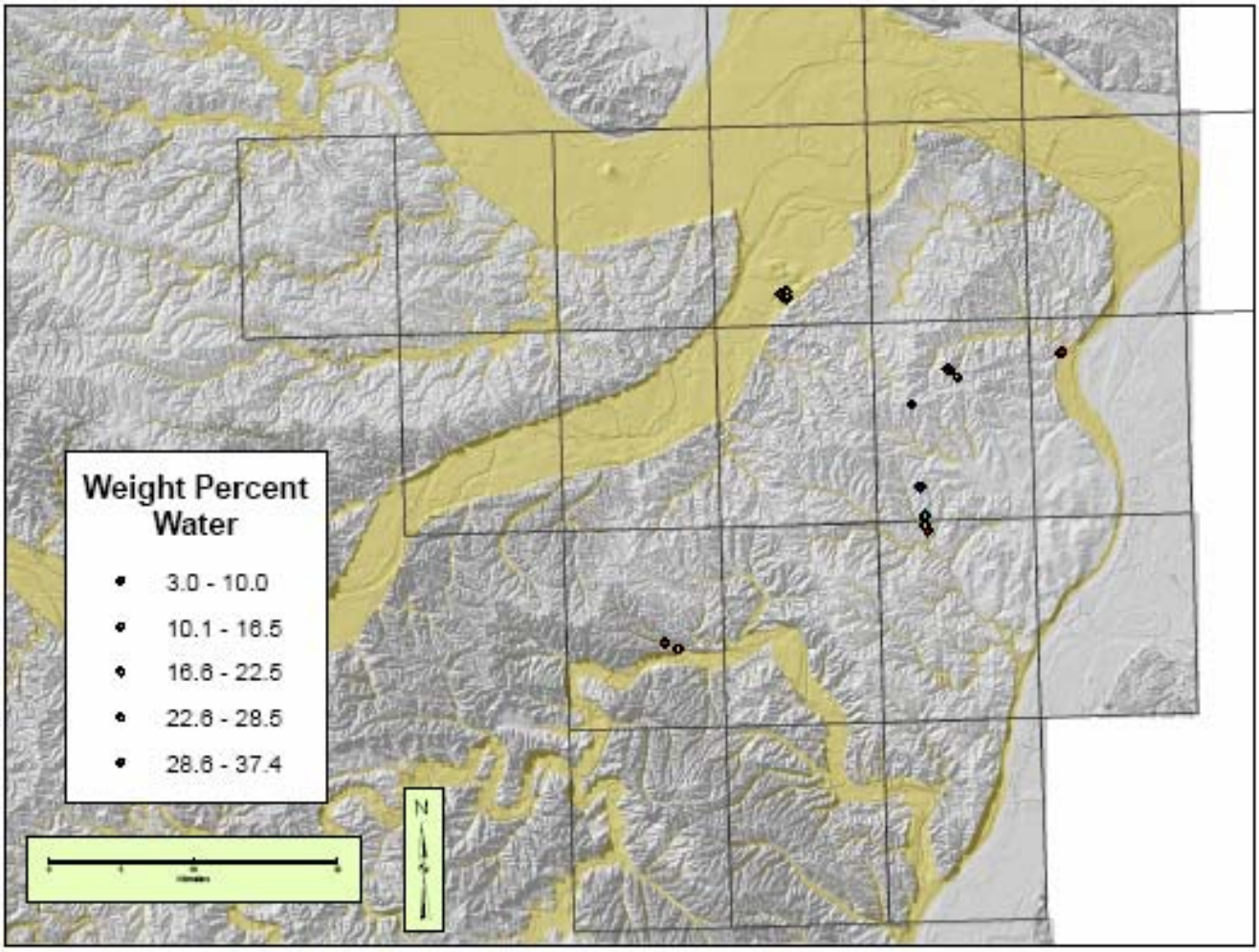


Figure 6. Weight Percent Water.

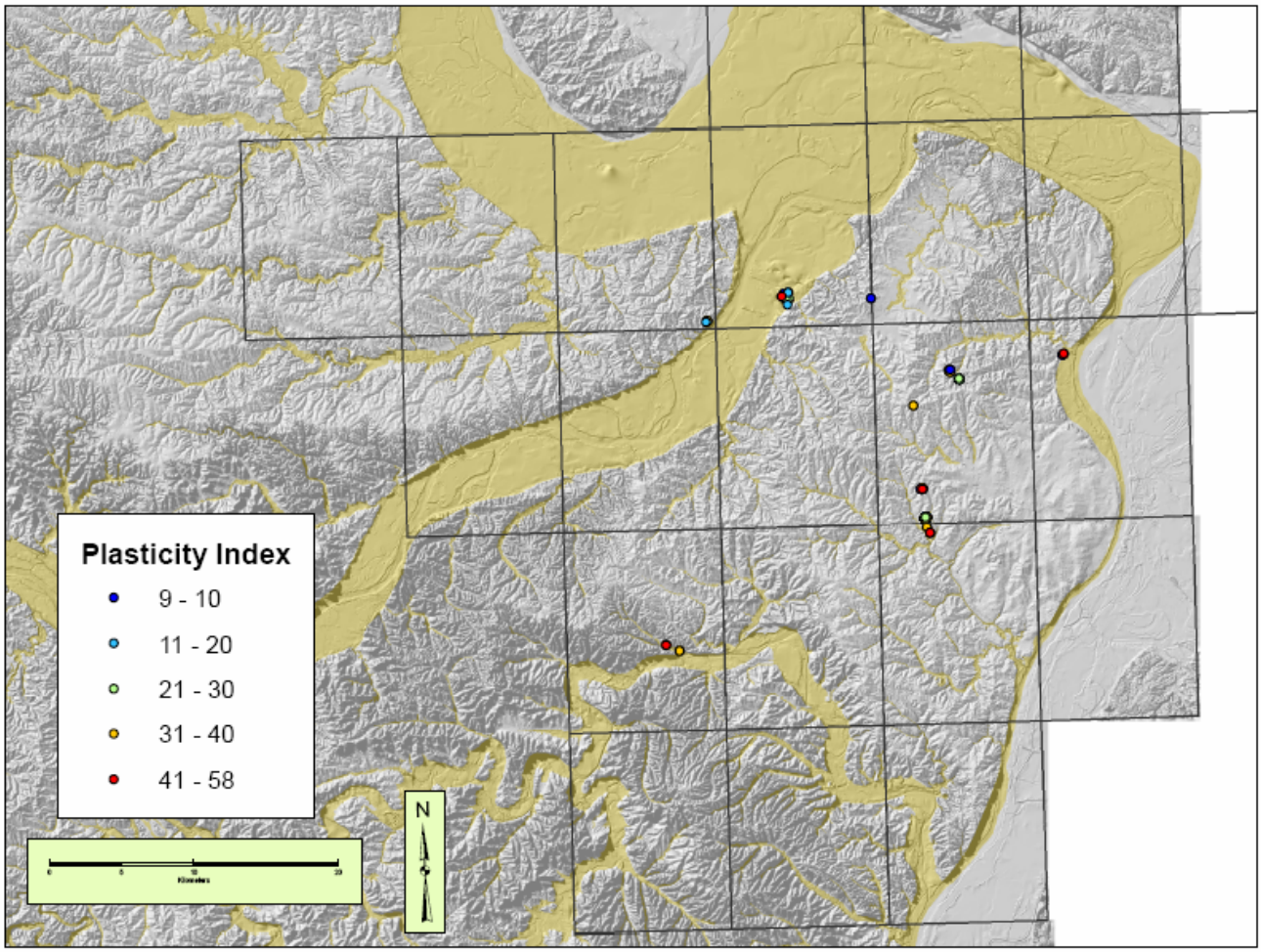


Figure 7. Plasticity Index Data. Lowest values shown for each boring.

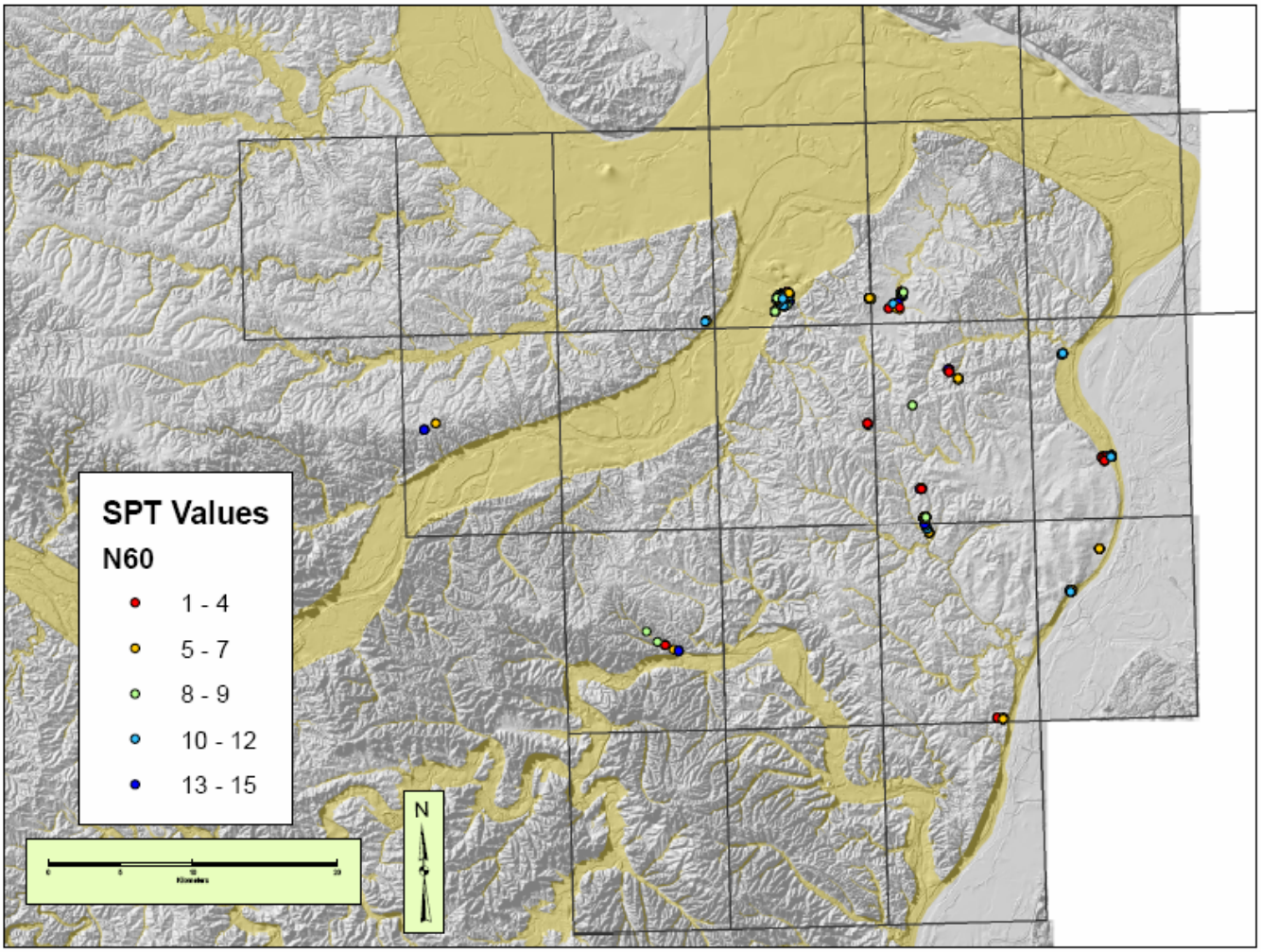


Figure 8. Standard Penetration Test N60 Values. Of the 135 borings that have SPT data, none have N60 values greater than 15.

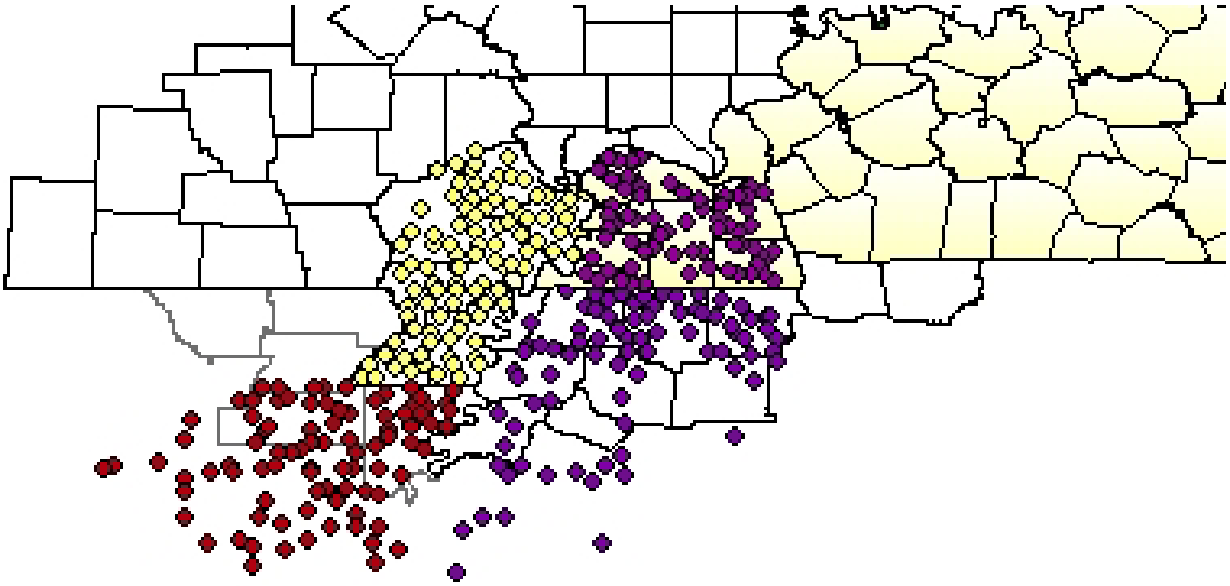


Figure 9. 500+ locations of shear wave velocity measurements that have been added to Kentucky Geological Survey's database. Yellow counties are in Kentucky.

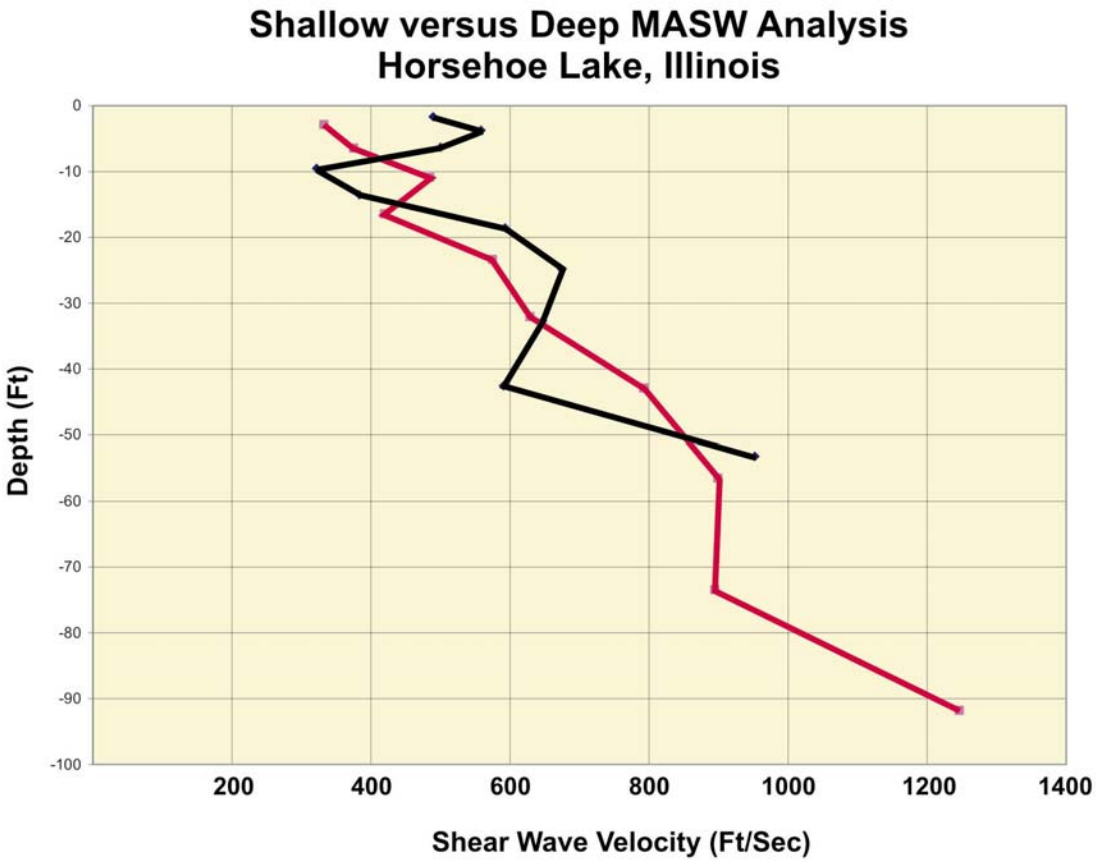


Figure 10. Comparison of the same MASW measurements processed for two different depths (University of Missouri-Rolla, David Hoffman).

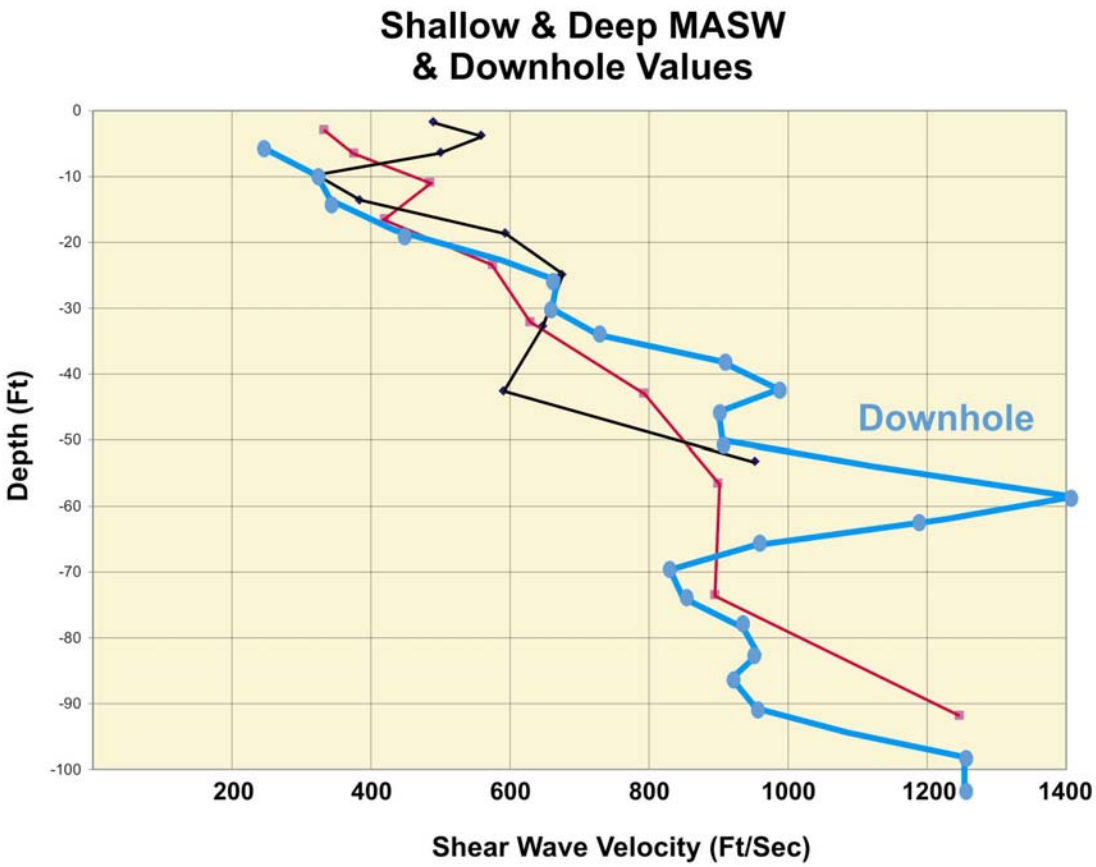


Figure 11. Comparison of Downhole shear wave velocity measurements to the MASW analysis shown in Figure 10.

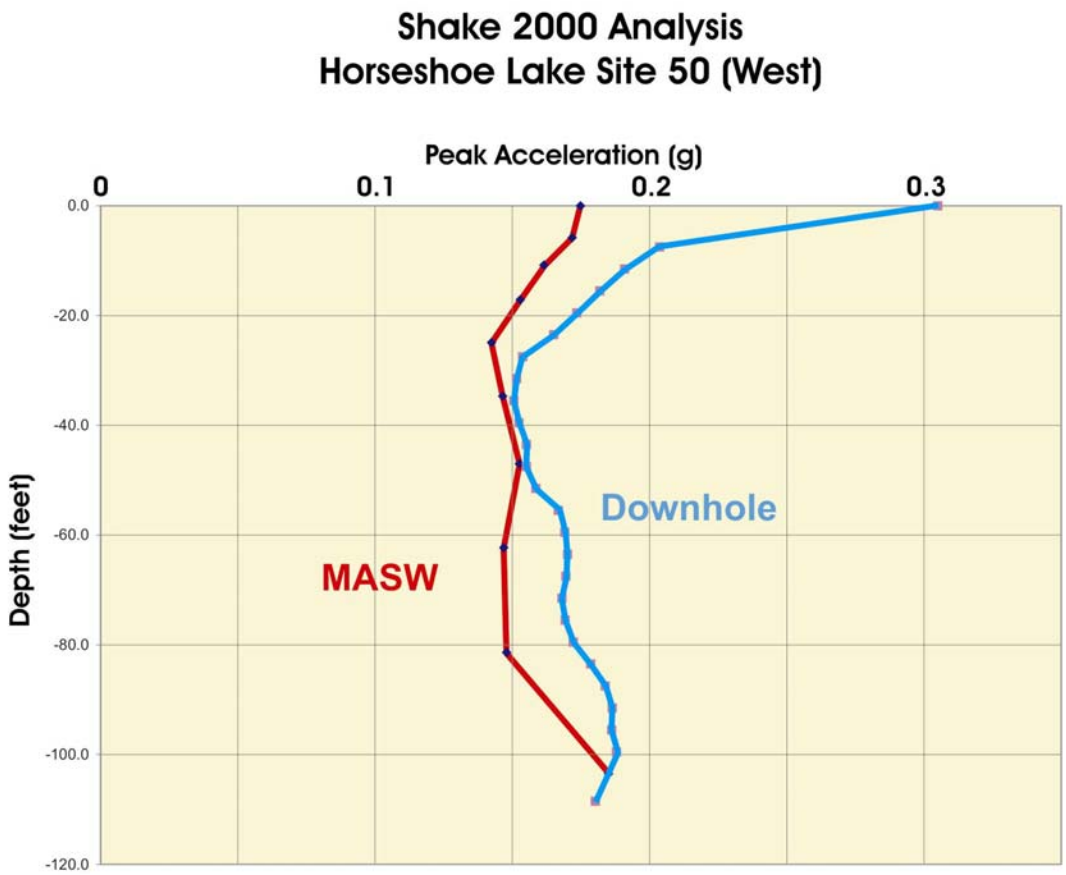


Figure 12. Shake 2000 analysis (using Shake91) of MASW and Downhole shear wave velocity measurement of the same borehole.

Table 1. Comparison of classification of soil profile type using several different methods based on the shear wave velocity measurements of the same borehole by MASW and Downhole methods.

Soil Profile Type Determination by Method

	Downhole	MASW Deep	MASW Shallow
Average NEHRP Velocity	**572 ft/sec**	**643 ft/sec**	**557 ft/sec**
NEHRP Soil Type Based on Average	**E**	**D**	**E**
Amplification based on Shake91	**1.7**	**0.97**	
Soil Profile Type based on Amp.	**D**	**B**	