FINAL TECHNICAL REPORT
Award Number: G14AP00023 and G14AP00024

Title: "Charleston Area Earthquake Hazards Mapping Project (CAEHMP) Workshop and Pilot Study: Collaborative Research with the College of Charleston and the University of Memphis"

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January 15, 2014 – January 14, 2015

Submitted: April 15, 2015

"Research supported by the U.S. Geological Survey (USGS), Department of Interior, under USGS award numbers G14AP00023 and G14AP00024. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government."

Abstract

In 2014 we established a Charleston, SC Area Earthquake Hazard Mapping Project (CAEHMP) via an initial workshop and pilot study. The goal of the workshop was to bring together the interested technical and user communities into a technical working group (TWG) to review past and current earthquake hazard research and define the scope, products, and outreach efforts of CAEHMP. CAEHMP is patterned after similar successful urban seismic hazard mapping projects in St. Louis, MO-IL, Evansville, IN, and Memphis, TN. An establishing TWG workshop was held on March 5-6, 2014 at the College of Charleston to define project scope and efforts. The workshop resulted in project scope and planning documents for the CAEHMP.

A pilot study for developing urban hazard maps for the Charleston, SC area was conducted in 2014. Urban seismic and liquefaction hazard maps include the effects of local geology. In our pilot study we have used published and available geological, geotechnical, and geophysical information to develop an initial 3D community model for the Charleston quadrangle. The pilot study model includes four alternative Quaternary soil profiles and a deep reference profile for the Tertiary (Cooper Marl) to the Mesozoic bedrock. The South Carolina dynamic soil properties of Zhang et al. (2005,2008) were used in the soil response analysis. Equivalent linear and nonlinear soil response computer programs were evaluated for use in the Charleston urban-hazard mapping project. Site amplification distributions as a function of hard-rock input ground motion indicate significant deamplification at strong ground motion levels both at short and long periods due to nonlinear soil behavior in soft soils. Probabilistic seismic hazard maps were generated using the approach of Cramer (2003, 2011). Initial 2% in 50 year probabilistic seismic hazard maps indicate hazard levels of 0.25-0.35g for peak acceleration, 0.30-0.55g for 0.2 s spectral acceleration (Sa), and 0.3-0.50g for 1.0 s Sa. Seismic hazard seems correlated with Quaternary soil thickness over the Tertiary Marl. At short periods increasing thickness correlates with decreasing hazard due to nonlinear soil behavior. At long periods increasing thickness correlates with increasing hazard due to soil resonance. The liquefaction probability curves of Heidari (2011) are used to generate liquefaction hazard maps using the probabilistic approach of Cramer et al. (2008).

Introduction

Statewide seismic hazard maps that include the effect of regional geology have been produced by Silva et al. (2003) for the State of South Carolina, and Chapman and Talwani (2006) for the South Carolina Department of Transportation. These statewide maps model the thickening Atlantic coastal sediments and the general distribution of thinner sediments inland, but do not model the detailed shallow geology needed for urban seismic hazard maps. In recent years new studies have improved the understanding of both seismic site response (Andrus et al., 2006; Chapman et al., 2006) and liquefaction potential (Hayati and Andrus, 2008; Heidari and Andrus, 2010; Juang and Li, 2007) in the Charleston, SC region. The studies cited above are based mainly upon geotechnical data in the Charleston region. Ground motion records from the Charleston region are still scarce. A small but growing number of records from both local (e.g., Dec. 16, 2008 M = 3.6 Summerville, SC) and regional (e.g., Aug. 23, 2011 M = 5.8 Mineral, VA) earthquakes have been recorded at the four ANSS strong motion sites in Charleston. These sites have been characterized by both geotechnical and surface seismic means (Jaumé, 2006). New ambient noise ground motion records also exist at ~75 sites in Charleston, most close to locations of pre-existing geotechnical boreholes (Miner and Jaumé, 2011). Horizontal to vertical spectral ratio (HVSR) estimates of resonance frequencies from ambient seismic noise match estimates derived from geotechnical data at frequencies < 2 Hz but disagree at higher frequencies (Jaumé and Miner, 2011). Work still needs to be done to bring the geotechnical and seismic estimates of site response into agreement, which has been done successfully in other areas (e.g., Motazedian et al, 2011).

As part of this grant, we held a workshop to gain input from the technical and user communities in the Charleston, SC area. We also conducted a pilot study for the Charleston Quadrangle to test approaches to hazard modeling for CAEHMP and provide initial urban seismic and liquefaction hazard maps for the Charleston quadrangle. The first part of this report discussed the workshop and its products. The second part discussed the pilot study and its results.

Inaugural Workshop and Follow Up Meetings

On March 5-6, 2014 a Charleston Area Earthquake Hazards Mapping Project (CAEHMP) workshop was held to initiate a Technical Working Group (TWG) to support and advise the CAEHMP effort (see Appendix A for workshop agenda). The goals of the workshop were to evaluate the availability of needed information, obtain feedback from the user community concerning their needs, and to develop a scope of work for the project. The 25 workshop participants represented a diverse group of stakeholders, including academic and government scientists, local and state emergency management officials, and engineering and geotechnical firms, etc (see Appendix B for list of attendees). Topics covered during the workshop included the role of the TWG, projected growth in the region, elements of urban hazard mapping, status of needed technical information, status of USGS seismic hazard model, review of possible products, possible outreach efforts, data management issues, and discussion of project scope. Direction provided by the TWG during the workshop included the development of a community geology/geotechnical/geophysical velocity model, a user community request for a time history (time series or waveform) database specific to the Charleston, SC region, the generation of probabilistic and scenario seismic and liquefaction hazard maps based on the soon to be released

2014 USGS National Seismic Hazard Mapping Project model, the specifying of a study region defined by potential data availability, the inclusion in the TWG of additional user community representation (SCDOT, Chamber of Commerce, major businesses like Boeing, etc.), the generation of appropriate HAZUS loss/risk analyses, the specifying of an outreach program, and the creation of a information/data serving and archiving system with public access. State-of-the-art methods and procedures should be used in accomplishing these tasks. The conveners of the workshop (Steve Jaume and Norm Levine of the College of Charleston, and Chris Cramer of CERI at the University of Memphis) were tasked with developing a two year scope of work for consideration at the next TWG conference call (April 22, 2014) and for use as the basis of follow-up USGS NEHRP proposals (due May 22, 2014). The Scope of Work document developed by the TWG is presented in Appendix C. Three proposals by TWG participants were submitted to the USGS NEHRP external grants program.

The inaugural workshop was followed by 4 conference calls and 3 quaterly in-person meetings of the TWG. All of the one day in-person meetings were held at the College of Charleston. These conference calls and meetings allowed the PIs to brief TWG participants on the progress of the pilot study and for the TWG to offer critiques and guidance to the PIs. The results of the Pilot Study reported herein reflects the guidance of the TWG.

Pilot Study

Hazard Mapping Methodologies

Earthquake ground motions at any location basically depend on the size of the earthquake (magnitude), how ground motions decay with distance from the earthquake faulting (attenuation with distance), and how soils beneath a site increase or decrease certain frequencies in the ground motion (site amplification based on local geology). Earthquake hazard basically depends on the rate at which earthquakes occur in the region surrounding a site (recurrence) and the magnitudes of those earthquakes. Larger earthquakes have bigger associated ground motions over a wider area and hence can cause more damage and pose a greater hazard than smaller earthquakes. Thus earthquake hazard is dominated by the rate of large earthquakes (magnitude 7's in the central and eastern U.S). For the Charleston seismic zone, dated paleoliquefaction features indicate that M7 earthquakes occur on average every 550 years (Talwani and Schaeffer, 2001), which poses a significant hazard in the eastern U.S.

Probabilistic seismic hazard estimates answer the question "What is the likelihood of a given level of ground shaking being exceeded at a site?" This involves knowing where the earthquakes occur in the region (the distance to each earthquake source from the site), their distribution of magnitudes and how often they occur for each earthquake source (magnitude-frequency distribution), and how big the ground motion is for every earthquake's magnitude and distance from the site (ground motion attenuation relation). The national seismic hazard maps combine the probabilities from these distributions for each earthquake source in the region, but do so for a uniform soil condition (amplification). That is, the national maps do not take into account the effects of local geology on earthquake ground motions, but only consider one site condition that is rare in the CEUS (unlikely to be pertinent).

Urban seismic hazard maps do add in the effect of local geology on the amplification of earthquake ground motions in order to have more realistic ground motions for earthquake hazard analysis within the study area. To do this, information is needed about the local distribution and thicknesses of soil in the urban area. Basically, two pieces of information are needed: what are the thicknesses at a site of each soil type (lithology) and what are each soil type’s physical (geotechnical) properties that effect ground motion amplification. Site amplification at a site is determined by taking a soil profile (soil type, thicknesses and physical properties) and subjecting that soil profile to earthquake shaking (time history) in the solid rock at the bottom of the soil profile to calculate the expected shaking at the surface of the ground. The change in amplitude of the shaking from the bottom to the top of the soil profile is site amplification.

Figure 1 provides a generalized picture of how all the earth science and geological/geotechnical information currently comes together to generate urban seismic ground motion hazard maps. A lot of disparate information needs to be developed and brought together from a variety of disciplines and sources. Validation and quality control of the information developed must occur for the urban hazard maps to be realistic and beneficial. And the information and procedures must reflect our current understanding and the best available science to be credible so the products can be used with confidence.

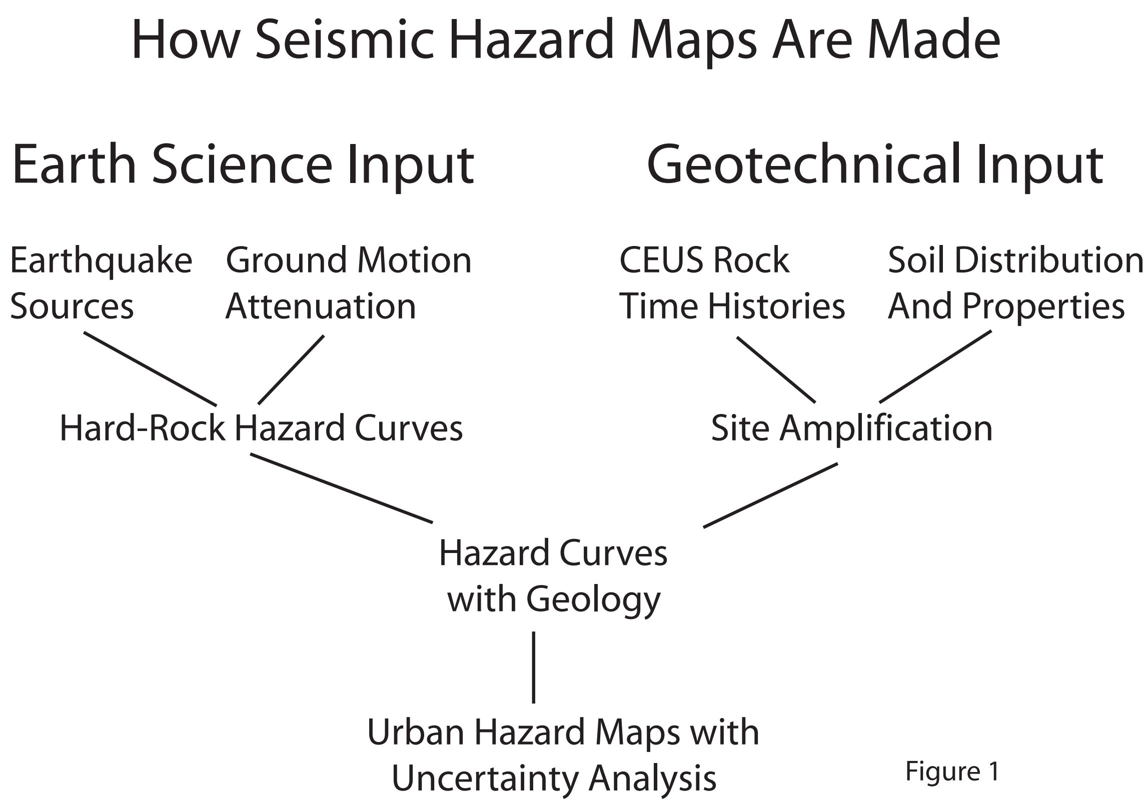


Figure 1

The Memphis and St. Louis urban hazard mapping projects are providing urban seismic hazard maps for 12 and 29 quadrangles. For such a large number of quadrangles, the seismic hazard calculations with the effects of local geology need to be made efficiently, as they are being done on a dense, ~500 m grid. For a given site, the probability, P(A > Ao), of exceeding a specific ground motion Ao (Reiter, 1990, equation 10.2) is given by the seismic hazard integral

$$P(A > Ao) = \sum_I \alpha_I \int_M \int_R f_I(M)\, f_I(R)\, P(A>Ao \mid M,R)\, dR\, dM, \qquad (1)$$

where A is a ground-motion parameter (i.e., peak ground acceleration, PGA, or spectral acceleration, Sa), Ao is the ground motion level to be exceeded, α_I is the annual rate of occurrence of the ith source, M is magnitude, R is distance, $f_I(M)$ is the probability density distribution of earthquake magnitude of the ith source, and $f_I(R)$ is the probability density distribution of distance from the ith source. Originally, hazard at a site (grid point) is calculated by applying the appropriate site amplification distribution P(As | Ar) to the ground-motion attenuation relations within the hazard integral so as to alter them to site-specific attenuation relations (Cramer, 2003, 2005). Thus, in equation 1, A = As and P(A>Ao | M,R) becomes P(As>Ao | M,R) for a soil site, and

$$P(As>Ao \mid M,R) = 1 - \int_{Ar} P(As \leq Ao \mid Ar)\, P(Ar \mid M,R), \qquad (2)$$

where

$$P(As \leq Ao \mid Ar) = \int_{As:-\infty \rightarrow Ao} P(As = Ao \mid Ar)\, dA \qquad (3)$$

and

$$P(Ar \mid M,R) = d[1 - P(A > Ar \mid M,R)] / dA. \qquad (4)$$

Basically the site amplification distribution alters the rock hazard curve to a soil hazard curve for each earthquake in the hazard model before they are summed into the final soil hazard curve.

Lee (2000) has shown that instead of modifying the hazard curve of each earthquake in the hazard model and summing the resulting site-specific hazard curves to obtain the total site-specific hazard curve, the total hazard curve from the hard-rock hazard calculation can be modified directly by the site amplification distribution to make it site-specific:

$$P(As > Ao) = 1 - \int_{Ar} P(As \leq Ao \mid Ar)\, P(Ar), \qquad (5)$$

where P(As $\leq$ Ao | Ar) is given by equation 2, and P(Ar) is from the total hard rock hazard curve and is given by

$$P(Ar) = d[1 - P(Ar > A)] / dA. \qquad (6)$$

This can be done because the site amplification distribution is explicitly independent of earthquake magnitude and distance and thus can be pulled outside of the seismic hazard integral (equation 1). It may seem that nonlinearity in soil response is implicitly dependent on magnitude and distance, but engineering models of nonlinear response are only dependent on the input level of ground motion. Further, the nature of the total hazard curve emphasizes that the strong ground motions come from the nearest, largest earthquakes and hence nonlinear soil behavior being a function of ground-shaking strength. Comparisons between these two approaches at the Savannah River Site indicate that both approaches yield essentially the same hazard result (Lee, 2006, personal communication) and tests have shown a greater than 5 times savings in computational time.

Implementing this seismic hazard mapping methodology requires the development of a 3D geological and geotechnical model plus reference or grid-specific Vs profiles (Cramer et al., 2004, 2006). Via a Monte Carlo randomization procedure, site amplification distributions are developed at each grid point for each ground motion period for which hazard maps are developed (usually peak ground acceleration and 0.2, 0.3, and 1.0 s spectral acceleration). This is accomplished using an equivalent linear or nonlinear soil response program. The choice of program is dependent on how far the study area is from seismic sources and the expected ground motions from those sources. These site amplification distributions are relative to bedrock (hard rock conditions). Thus a database of geological, water well, and geotechnical borings and geophysical measurements must be developed for this methodology. This methodology provides more realistic ground motion and liquefaction hazard estimates than the common engineering practice of using NEHRP site amplification factors that are incorporated into building codes. Loss estimates based on these improved ground motion estimates should also be more realistic.

Seismic hazard maps with the effect of local geology are the basis for generating liquefaction hazard maps. To generate probabilistic liquefaction hazard maps, the final CAEHMP PGA seismic hazard maps and associated data are incorporated using the approach of Cramer et al. (2008), which was developed for the Memphis urban hazard-mapping project. Note that the liquefaction cumulative probability curves are a function of magnitude and hence are used inside the hazard integral to calculate probabilistic liquefaction hazard maps as indicated in the following equation from Cramer et al. (2008):

$$P(P_{LPI>n} > Po) = \Sigma_i \, \alpha_i \int_M \int_R f_i(M)\, f_i(R)\, P(P_{LPI>n} > Po \mid A>Ao,M)\, P(A>Ao \mid M,R)\, dR\, dM \qquad (7)$$

where $P(P_{LPI>n} > Po)$ is the liquefaction hazard curve for LPI>n, α_i is the rate of source i, M and R are magnitude and distance, $f_i(M)$ and $f_i(R)$ are the ith source magnitude and distance distribution functions, $P(P_{LPI>n} > Po \mid A > Ao,M)$ is the liquefaction cumulative probability curve for the site and LPI>n, and $P(A > Ao \mid M,R)$ is the site-specific attenuation relation. Figure 2 shows how the various geological, seismological, and geotechnical elements are brought together to produce liquefaction hazard maps. The generation of final liquefaction hazard maps requires the use of a GIS, guided by the surface geology map, to piece together liquefaction hazard maps for each surface soil type into a scenario or probabilistic liquefaction hazard map.

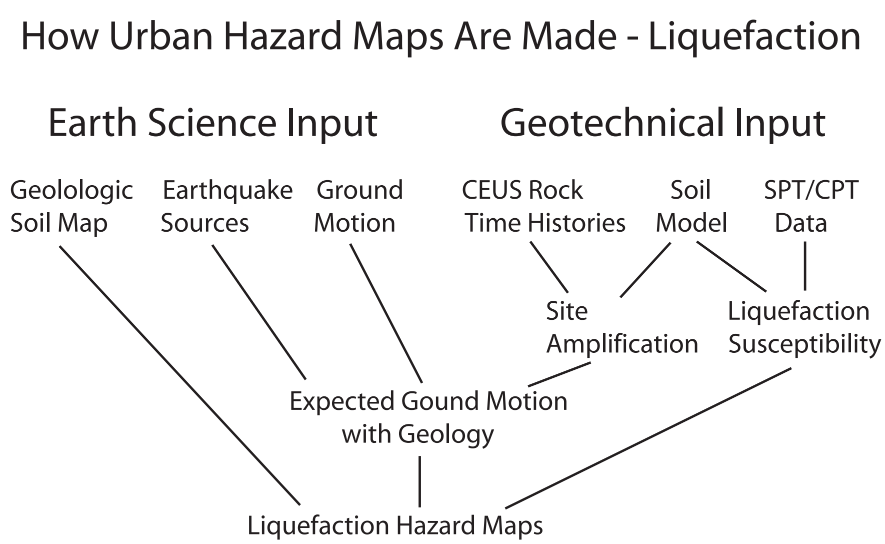


Figure 2

Community Velocity Model

The Technical Working Group began development of a Community Velocity Model for the greater Charleston region by compiling existing information on shear wave velocities of the sedimentary materials underlying the South Carolina coastal plain. For the most part, direct V_S measurements in the Charleston region are confined to the upper 100 meters of the sedimentary column, and that for the deeper section only indirect V_S estimates exist. In the following discussion, we review the existing Community Velocity Model, how it was determined, and plans for future refinements of the model. The discussion will start with the deepest part of the sedimentary section and proceed upwards.

Shear-wave velocity of deep (>100 meter) sedimentary materials

Coastal plain sediments in the Charleston region consist of late Cretaceous and younger sediments overlying Jurassic-Triassic volcanics and rift-basin sediments (Heffner et al., 2011). Several groups have developed models for the V_S structure of the coastal plain section, including Andrus et al. (2006), Chapman et al. (2006) and Wong et al. (2005). It was found that, at depths greater then 100 meters, the Andrus et al. (2006) and Wong et al. (2005) V_S models either simply gradually increase from V_S measured at shallow depths (Andrus et al.) or use measured velocities from other locations (Wong et al.) to extrapolate V_S at depth. Chapman et al. (2006) used measured V_P/V_S ratios of 3 derived from P-to-S conversions seen in earthquake seismograms from the Middleton Place-Summerville Seismic Zone (Chapman et al., 2003) and combined this with P-velocity estimates from a sonic log of the Clubhouse Crossroads borehole (Gohn, 1983) to develop estimates for V_S of the coastal plain sediments below ~100 meters depth. The Chapman et al. (2006) V_S model was judged to be the best constrained by seismic data from within the study region, and was adopted for the Community Velocity Model for depths >100 meters.

Shear-wave velocity from 100 meters to the Quaternary/Tertiary interface (5-30 meters)

The V_S of this part of the sedimentary section is better constrained, with several suspension log measurements to depths of ~100 meters. Both Andrus et al. (2006) and Chapman et al. (2006) make use of this data, with Andrus et al. (2006) combining measurements from all available suspension logs while Chapman et al. (2006) used only the log associated with the main pier of the Cooper River Bridge. Most importantly, Andrus et al. (2006) was able to characterize V_S of the entire Tertiary section from its shallowest occurrence (~7 meters) down to 100 meters. This velocity profile also matched that of Chapman et al. (2006) at a depth of 100 meters (V_S ~ 660 meters/second). Therefore it was decided to splice the two models at a depth of 100 meters. This V_S model is shown in Figure 3.

During the course of the March 2014 workshop it was noted that a relatively new V_S log down to 137 meters is also now publically available, and was used in seismic site factor study by Aboye et al. (2013). This profile was found to be very similar to that of Andrus et al. (2006), with V_S ~400 meters/second at the top of the Tertiary increasing to ~650 meters/second at 80 meters depth.

V_S and thickness of the Quaternary section

Numerous borehole and surface geophysical estimates of V_S exist for the Quaternary sediments in the Charleston region. Several previous authors (e.g., Andrus et al., 2006; Chapman et al., 2006) compiled the existing V_S estimates in their site response studies. For our purposes, we found it necessary to reorganize this existing data to produce the initial urban seismic hazard maps shown below. In particular, we grouped the existing V_S estimates according to surface geology types (Figure 4). Some map units had too few V_S estimates to analyze them independently; the data from these units were combined with that from other surficial units of similar age. Our final surficial map units and their average shear-wave velocity with depth are shown in Table 1. We were able to derive well-constrained average V_S estimates to at least 20 meters depth for two of the four surficial units and 25 meters depth for the other two. In those locations where the thickness of the Quaternary exceeded the thickness for which we had V_S constraints, we simply took the V_S of the deepest layer and extrapolated it to the top of the Tertiary section.

Table 1: Estimated V_S (meters/second) for Quaternary surficial units as a function of depth (and their uncertainties) for the Charleston quadrangle (Figure A2).

Unit	af		Qh		Qsb		Qw	
Depth	Average	St. Dev	Average	St. Dev	Average	St. Dev	Average	St. Dev
0-5 m	153	75	148	69	168	53	177	46
5-10 m	153	68	134	53	172	57	182	54
10-15 m	149	59	171	52	205	44	208	47
15-20 m	163	49	201	56	252	35	207	51
20-25 m	198	51	NA	NA	NA	NA	233	21

af = artificial fill; Qh = Qal, Qhm, Qhs & Qht; Qsb = Qsbc & Qsbs; Qw = Qwc & Qws on Figure 4.

During the course of the project Technical Working Group member S&ME, Inc. provided us with V_S estimates at an additional 97 sites across the South Carolina coastal plain. Given the short time frame of the pilot study we were not able to incorporate these V_S estimates into our velocity model; that work is ongoing. We did, however, use this data to provide additional constraints on the elevation of the Quaternary/Tertiary (Q/T) boundary across the study area (see next paragraph).

The geotechnical borehole data cited above also helps constrain the elevation of the Q/T boundary across the Charleston region. We also added additional elevations from 594 auger holes collected by USGS researchers (i.e., those used by Weems and Lewis, 2002). For the Charleston quadrangle itself, this gave us a total of 440 estimates of the elevation of the Q/T surface inside and within 5 km of the quadrangle boundary. We used a natural neighbor algorithm in a geographical information system to interpolate the elevation of the Q/T surface across the Charleston quadrangle (Figure 5: Left). Inspection of the differences between the interpolated surface and the input depth estimates (Figure 6) show that for 90% of the sites the two match within 1 meter; however, mismatches of up to 5 meters occur and that underestimates of the depth occur more frequently than overestimates. We then estimated the total sediment thickness by determining the elevation difference between the extrapolated Q/T surface and a bare earth LIDAR-based digital elevation model developed at the College of Charleston (Figure 5: Right).

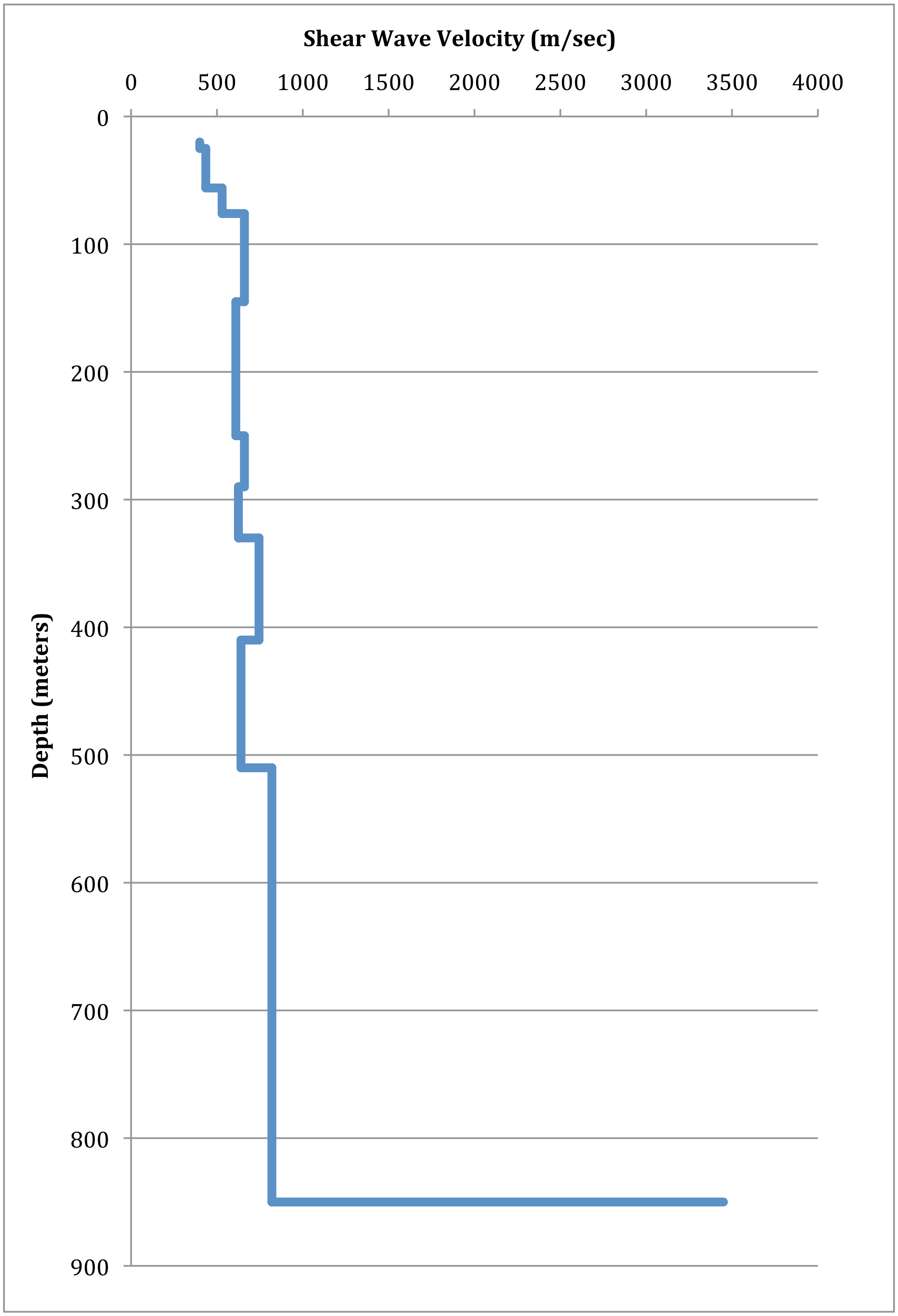


Figure 3: V_S profile used for the coastal plain sedimentary section below the Quaternary/Tertiary interface.

Future work

We plan to extend our Community Velocity Model across a 9 quadrangle area that includes both the current and projected high population zones in the greater Charleston metropolitan region (Figure 7). In addition to the geologic and geophysical borehole data cited above, there a large number of water wells in the study area. The South Carolina Department of Natural Resources maintains a database of these wells, and interrogation of this database reveals that 54 have geophysical logs (mainly gamma ray, but including resistivity and spontaneous potential). Many of these are logged to depths > 100 meters, with a maximum depth of ~770 meters (2532 feet). This information, together with available lithologic logs for these wells (Colquhuon et al., 1988),

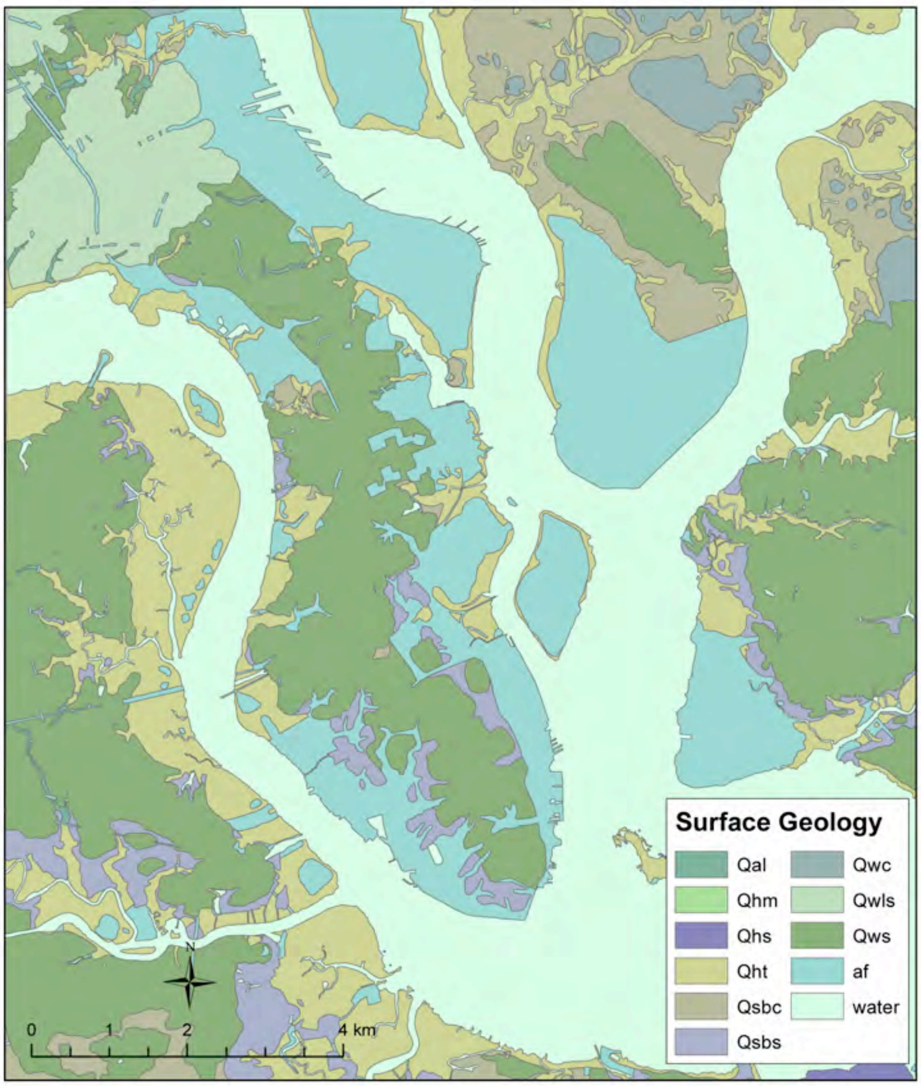


Figure 4: Surface geology map used in generating the Charleston quadrangle urban hazard maps of this report.

will be used to extrapolate geologic formation boundaries encountered in the Clubhouse Crossroads borehole across the study area. Available seismic reflection profiles (e.g., Chapman and Beale, 2010), one of intersects the Clubhouse Crossroads borehole, will be used in a similar fashion.

We will use the additional 97 geotechnical boreholes already collected, plus others that can be obtained from other geotechnical firms working in the study area, to characterize the V_S structure of the Quaternary deposits and the elevation of the Q/T boundary across the entire study area. A preliminary attempt to extrapolate the elevation of the Q/T boundary for the Summerville quadrangle (Figure 7) revealed that additional constraints beyond the available geologic and geotechnical boreholes are needed, particularly in existing wetland regions (i.e., Cypress and Four Hole Swamp). Consultations with local hydrogeologists suggest information on the elevation of the Q/T boundary in these regions may exist within state and federal forestry departments (T. Callahan, pers. comm.).

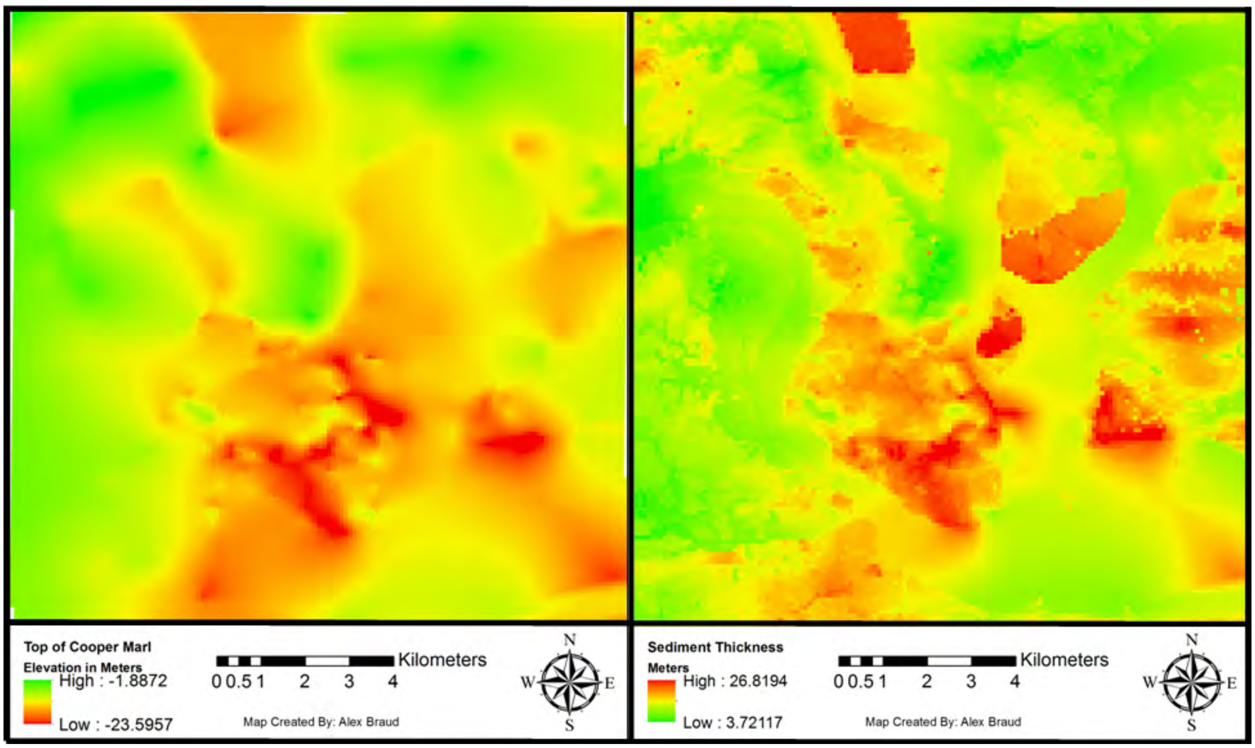


Figure 5: Left: Map of the elevation (in meters relative to MSL) of the top of the Cooper Marl (i.e., Q/T interface) extrapolated from borehole data. Right: Map of the thickness of Quaternary deposits, created by differencing the map on the left from a digital elevation model of the Charleston quadrangle.

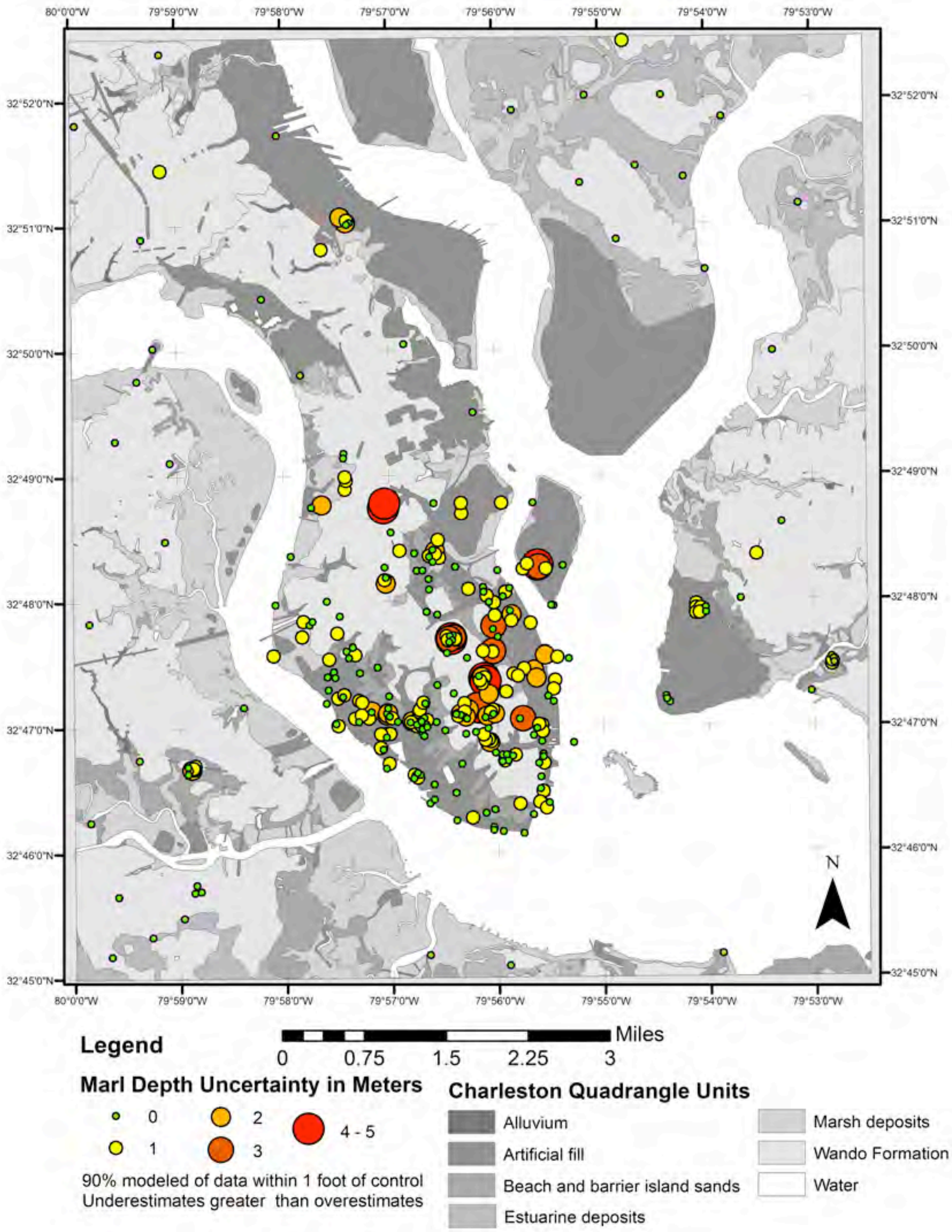


Figure 6: Mismatch between borehole estimates of depth of Cooper Marl and extrapolated top of marl surface (from Figure 5: Left). The largest mismatches (4-5 meters) tend to be in areas of greatest top of marl depth.

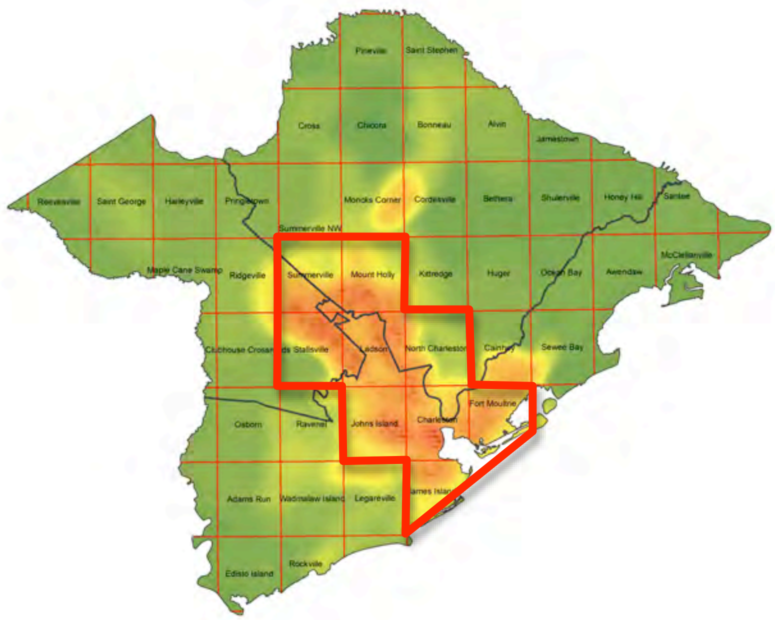


Figure 7: Population density (orange = greatest density) in Berkeley-Charleston-Dorchester county region. Red outlines 9 quadrangles enclosing the heavily populated area where we plan to extend the Community Velocity Model.

Soil Response Tests

As an initial step, we performed site response tests using equivalent linear and nonlinear soil response codes. Our initial effort used SHAKE91 (equivalent linear with frequency independent damping by Idriss and Sun, 1992), TREMORKA (equivalent linear with Kausel and Asimaki, 2002, frequency dependent damping by Bonilla, written communication, 2007), and NOAH-NL (nonlinear Iwan model by Bonilla, 2000) soil response programs. The version of NOAH we used in these tests uses modulus/damping curves like the equivalent linear programs, and does not include the dynamic pore-pressure effects model of the full NOAHW program (Bonilla, 2000; Bonilla et al., 2005). The SHAKE91 version we apply uses twice the precision in the calculations than the original program (see Cramer, 2006).

The soil profile used in these tests is the standard reference profile shown in Table 2. This standard model has the transition from 400 m/s to 435 m/s at 30 m instead of at 25 m for ease of incorporating Quaternary models with depths to the top of Cooper Marl (400 m/s) down to 25 m. This change from the measured profile is insignificant and has no impact on the site response as indicated in Figure 8.

Table 2: Standard soil profile for Charleston, SC used in soil response testing which combines the Quaternary and deep reference profiles. The first line is a description line. Negative numbers indicate metric units (m, gm/cc). Vs is shear-wave velocity.

Layer	Mod/Dmp #	Thickness (Depth-to-top)	Intrinsic Damping	Density	Vs
1	16	Charleston, SC Quaternary + Deep Ref. Profile			
1	1	-5.0 (-0)	0.050	-1.82	-155.00
2	1	-5.0 (-5)	0.050	-1.82	-153.00
3	1	-5.0 (-10)	0.050	-1.82	-203.00
4	1	-5.0 (-15)	0.050	-1.82	-276.00
5	1	-5.0 (-20)	0.050	-1.82	-276.00
6	2	-5.0 (-25)	0.020	-1.85	-400.00
7	2	-26.0 (-30)	0.020	-1.85	-435.00
8	3	-20.0 (-56)	0.020	-1.89	-530.00
9	3	-69.0 (-76)	0.020	-1.89	-660.00
10	4	-105.0 (-145)	0.010	-1.96	-610.00
11	4	-40.0 (-250)	0.010	-2.25	-660.00
12	4	-40.0 (-290)	0.010	-2.25	-625.00
13	4	-80.0 (-330)	0.010	-2.25	-745.00
14	4	-100.0 (-410)	0.010	-2.25	-640.00
15	4	-340.0 (-510)	0.010	-2.25	-820.00
16	10	(-850)	0.001	-2.80	-2800.0

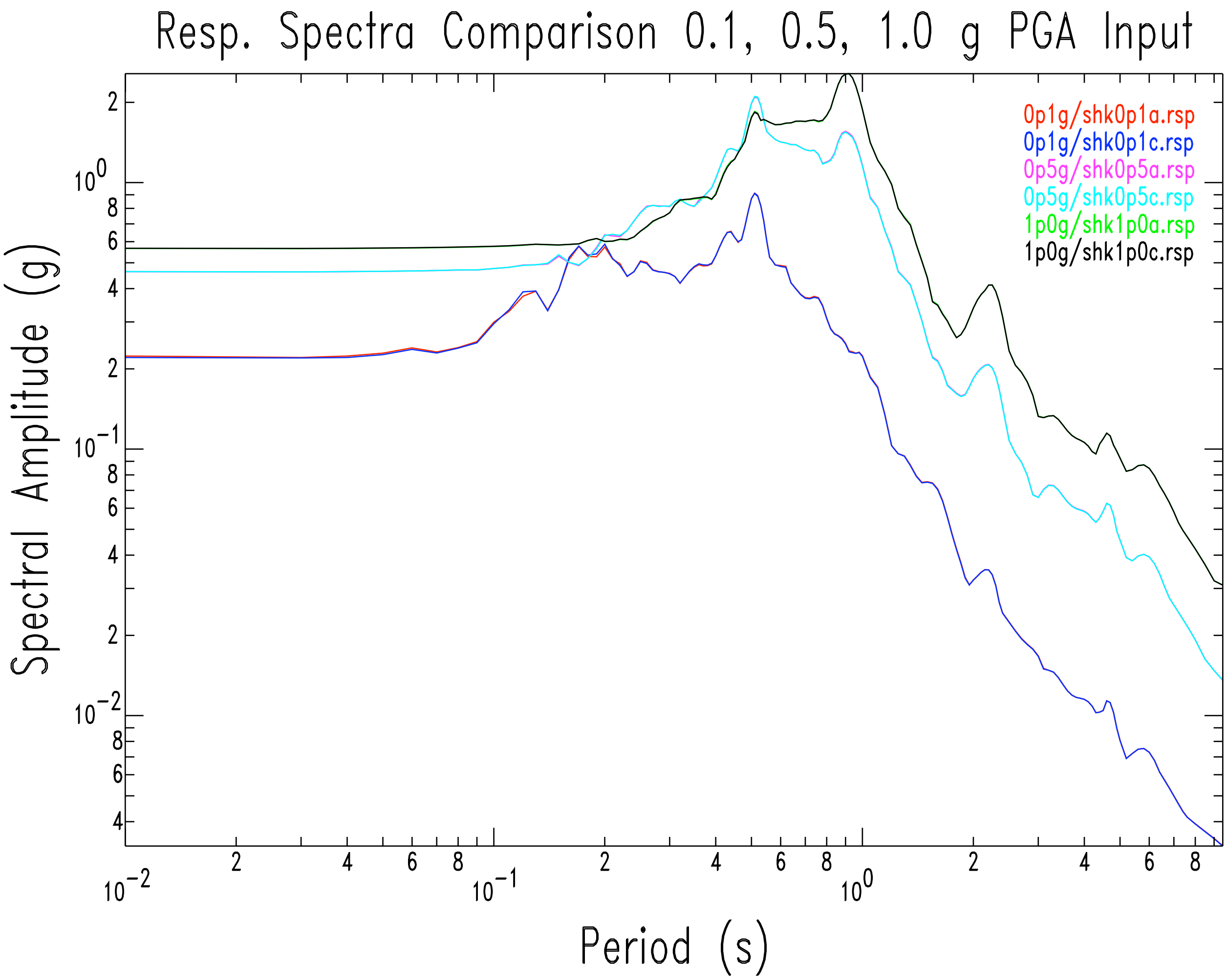


Figure 8: Soil surface response spectra for 0.1g, 0.5g, and 1.0g PGA input motion comparing the difference between the 400 m/s to 430 m/s transition at 25 or 30 m. SHAKE91 was used to calculate the response and the results are virtually the same for the two depth-to-transition options.

Using the dynamic soil and density model of Zhang et al., 2005, 2008, we calculated soil response using SHAKE91, TREMORKA, and NOAH-NL at three input levels (PGA at 0.1, 0.5, and 1.0 g). As an input ground motion time series (time history) for these tests, we used the recorded motion (radial component) at the rock site station LPCC (NEHRP B) from the 2010 M7.1 Christchurch, NZ earthquake at an epicentral distance of 40 km.

Figure 9 shows the results of these comparisons. For SHAKE91 we used three alternatives to nonlinear modeling of soil response: nonlinear allowed down to 100 m, down to 300m, and over the whole soil column. These alternatives are shown in 9. At 0.1 g PGA input ground motion (rock ground motion at the surface, which is reduced by a free surface factor of 2 for within rock ground motion at the base of the soil column), the soil response programs give similar response spectral results. At short periods (0.1 to 0.2 s or 5 to 10 Hz) the TREMORKA program predicts higher ground motions, while at long periods (greater than 0.5 s or less than 2 Hz) NOAH-NL predicts higher ground motions. SHAKE91 does a reasonably good job at the 0.1 g PGA input level. At 0.5 and 1.0 g PGA input ground motions, the comparison is similar with an increase in scatter among the alternatives. TREMORKA results at 1.0 g are not available due to a breakdown in the calculation. From Figure 9 we see that using SHAKE91 with nonlinear behavior limited to 300 m and above provides a reasonable alternative to the nonlinear results. The advantage of SHAKE91 is computational speed (fraction of a second per run versus more than a minute for NOAH-NL). SHAKE91 with a 300 m limit for the depth on nonlinearity was also used in the Memphis urban hazard maps (Cramer et al., 2004).

Figure 10 presents site amplification distributions from 200 Monte Carlo randomizations of the standard soil profile and using the time series alternatives of Cramer et al., 2006 for the suite of input ground motions. These are presented for PGA, 0.2 s spectral acceleration (Sa), and 1.0s Sa and were calculated using SHAKE91. Comparisons are made with the 1997 NEHRP soil factors. Clearly nonlinear soil behavior is strong at all periods above 0.2 g input ground motions and stronger than for the Memphis, TN area (see similar site amplification distributions for Memphis in Cramer et al., 2004).

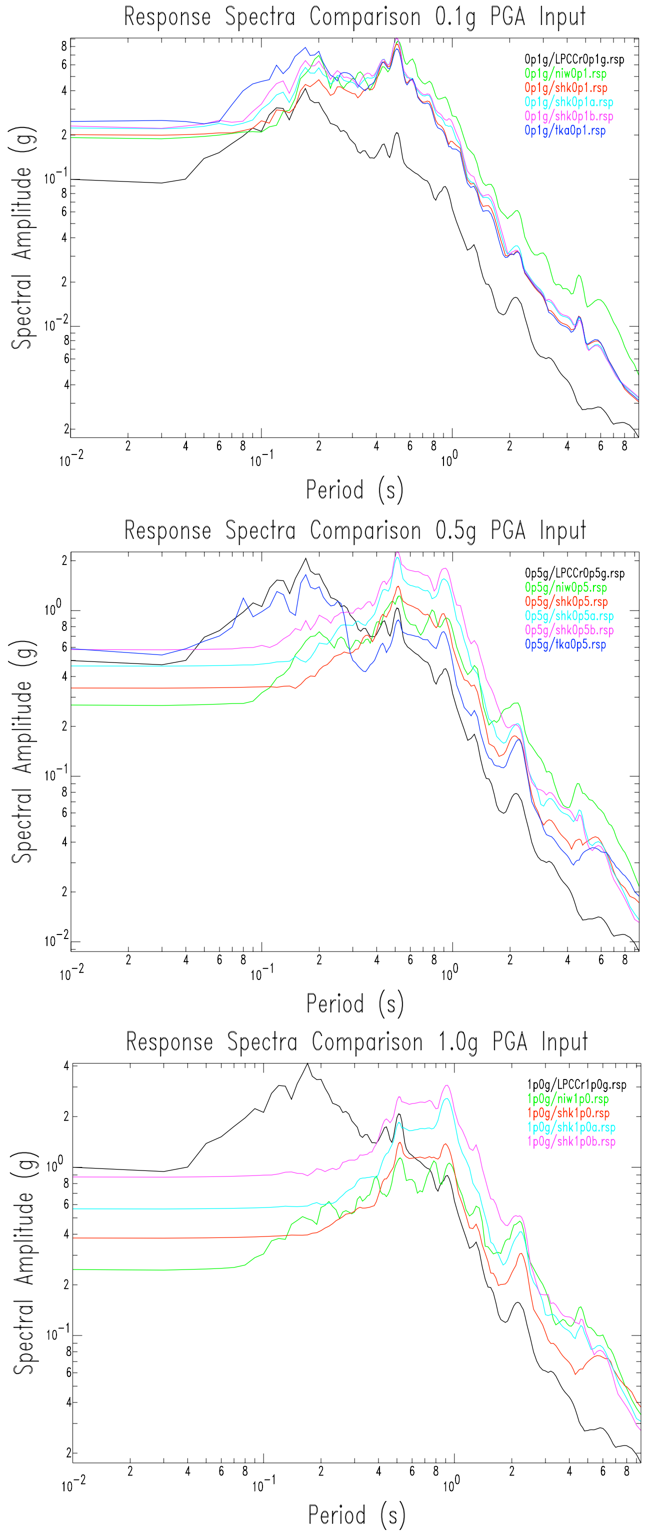


Figure 9: Comparison at 0.1 g (top), 0.5 g (middle), and 1.0 g (bottom) among three site response programs with three variations for SHAKE91. The black line is the input spectra, the green line is the NOAH-NL response, the red line is the SHAKE91 no limit response, the cyan line is the SHAKE91 300 m limit response, the magenta line is the SHAKE91 100 m limit response, and the blue line is the TREMORKA response.

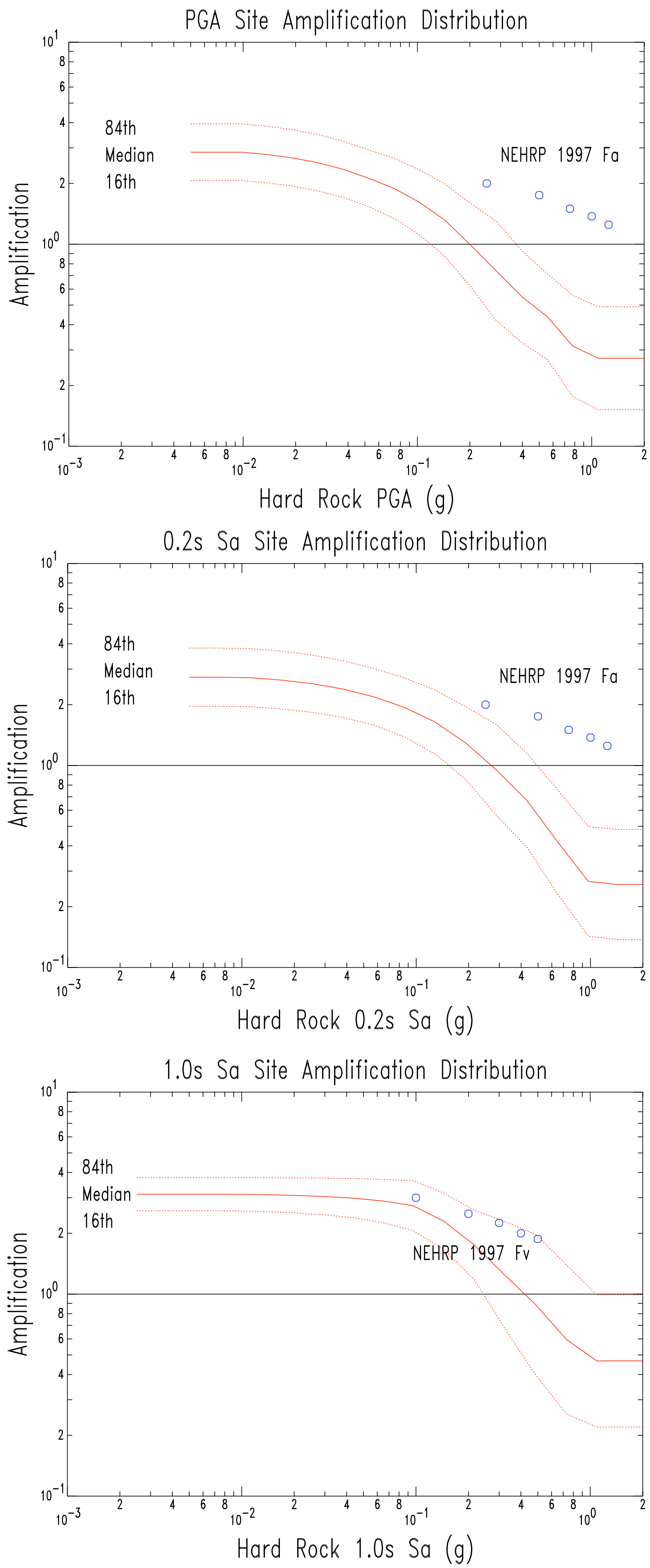


Figure 10: Site amplification distributions for PGA (top), 0.2s Sa (middle), and 1.0s Sa (bottom) for the Charleston quadrangle.

Initial Urban Seismic Hazard Maps

Urban hazard maps were calculated on a 0.5 km (500 m) grid using 200 Monte Carlo realizations of the soil profile at each grid point, Zhang et al. (2005, 2008) dynamic soil properties, and the suite of time series at epicentral distances less than 50 km used for the Memphis, TN urban hazard maps by Cramer et al. (2004). Site amplification distributions were calculated at each grid point for input ground motions of 0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, an 1.0 g for the period selected (PGA, 0.2 s Sa, or 1.0 s Sa in this case). The 2008 USGS National Seismic Hazard Mapping Project (NSHMP) model (Petersen et al., 2008) for sources and regional attenuation alternatives and weighting is used in calculating the urban hazard maps. The 2014 NSHMP was released in mid-2014 and was not available soon enough for use in this pilot study (all the necessary code changes were not completed until March 2015 under a separate USGS grant).

In this section we present initial probabilistic and scenario ground motion urban hazard maps for the Charleston quadrangle, which includes downtown Charleston, SC. First we will show the probabilistic maps, then discuss a Quaternary-soil thickness dependence in the hazard values, followed with scenario hazard maps for M7.0 and M7.3 earthquakes near Summerville, SC.

Probabilistic Seismic Hazard Maps

Figure 11 presents the 2%-in-50yr probabilistic hazard maps for the Charleston quadrangle at PGA, 0.2 s Sa, and 1.0 s Sa. The seismic hazard ranges from 0.3 to 0.4 g for PGA, 0.35 to 0.5 g for 0.2 s Sa, and 0.4 to 0.5 g for 1.0 s Sa. There seems to be some correlation of ground motion hazard with Quaternary soil thickness in the hazard maps that is discussed in the next subsection.

Companion probabilistic hazard maps for 5%- and 2%-in-50yr probability of exceedance are shown in Figures 12 and 13, respectively. For 5%-in-50yrs, hazard is ~0.2 g for PGA and ranges from 0.25 to 0.35 g for 0.2 s Sa and 0.2 to 0.3 g for 1.0 s Sa. For 10%-in-50yrs, the hazard is ~0.15 g for PGA, ~0.2 g for 0.2 s Sa, and ~0.15 g for 1.0 s Sa.

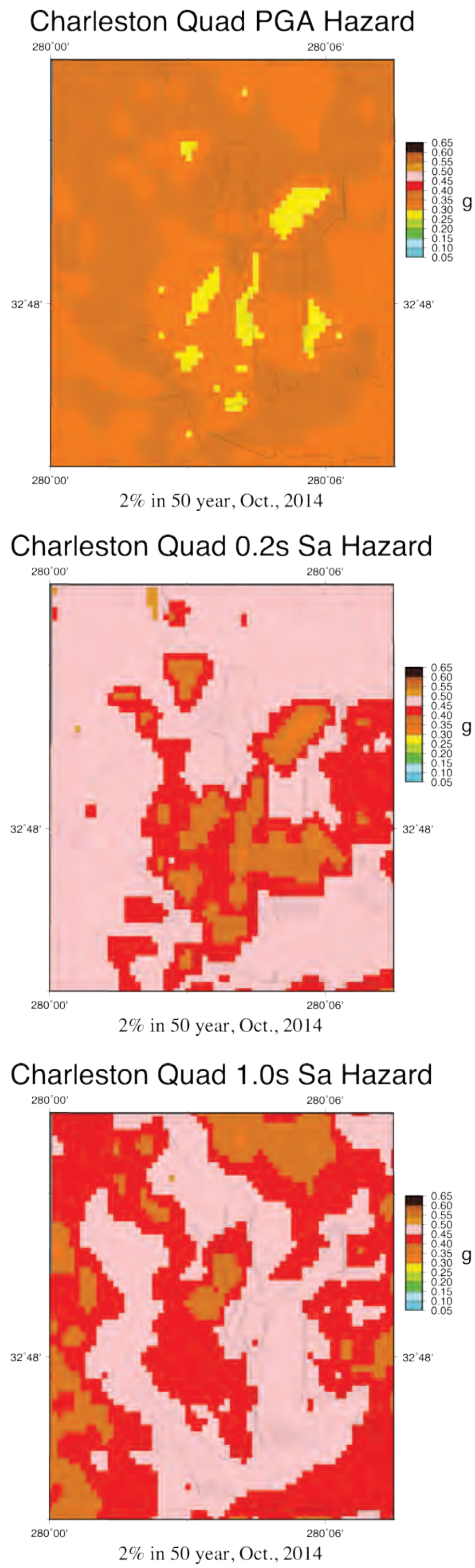


Figure 11: 2%-in-50yr seismic hazard maps for the Charleston quadrangle for PGA (top), 0.2 s Sa (middle) and 1.0 s Sa (bottom).

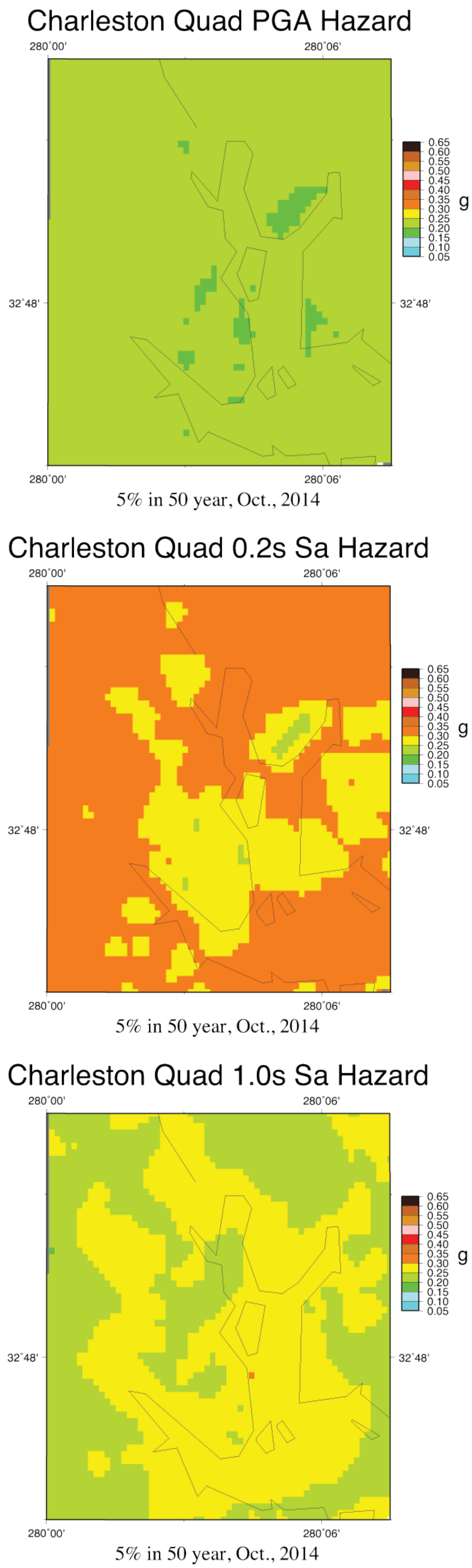


Figure 12: 5%-in-50yr seismic hazard equivalent of Figure 11.

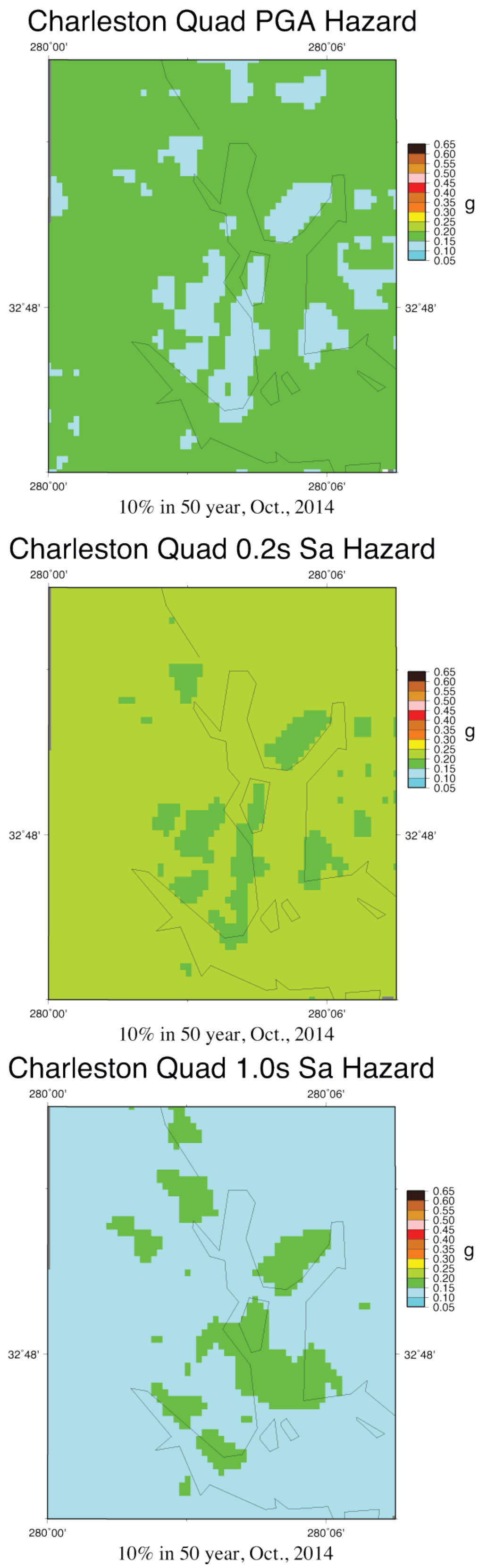


Figure 13: 10%-in-50yr equivalent to Figure 11.

Quaternary Soil Thickness Dependence

At least at the quadrangle scale level, there seems to be a hazard dependence on Quaternary soil thickness. At short periods (PGA and 0.2 s) 2%-in-50yr seismic hazard has a tendency to decrease with increasing Quaternary soil thickness over the Tertiary Cooper Marl, possibly due to nonlinear soil behavior at strong ground motion levels. At long period (1.0 s) the opposite seems true (increased hazard with increase thickness), possibly due to soil resonance effects.

This Quaternary soil thickness dependence is demonstrated in Figure 14. Generally for short periods, hazard decreases for thicknesses over 15 m, most dramatically for fill and least so for the Silver Bluff formation model. There maybe a similar decrease for thicknesses of 5 m or less. For long period, hazard increases with thickness up to 15 m and then levels off with fill showing a slight decrease over 15 m thickness. It is possible that these trends could be associated with the 5 m layer discretization in the Quaternary Vs models used in the hazard analysis. This would have to be checked using a finer Vs discretization.

The variability in seismic hazard across the Charleston quadrangle is ±0.02 g or less at any given depth level, which is within the uncertainty of the hazard models and analysis. This small variability could lead to a strategy for seismic hazard estimation using nonlinear soil response programs that run considerably longer than SHAKE91 for a given calculation/realization. Instead of running the randomizations using SHAKE91 at each of the 600+ grid points in a quadrangle (2000 runs per grid point per period), a reference profile for a type of surface geology could be run for 100 randomizations for selected Quaternary soil thickness values representing the expected range of soil thicknesses for each soil type. The resulting representative hazard vs. thickness curves could then be interpolated for calculating hazard at each grid point using the soil type and thickness at that grid point. This might make it feasible to calculate probabilistic seismic hazard estimates using a longer running nonlinear code like NOAH-NL or NOAHW.

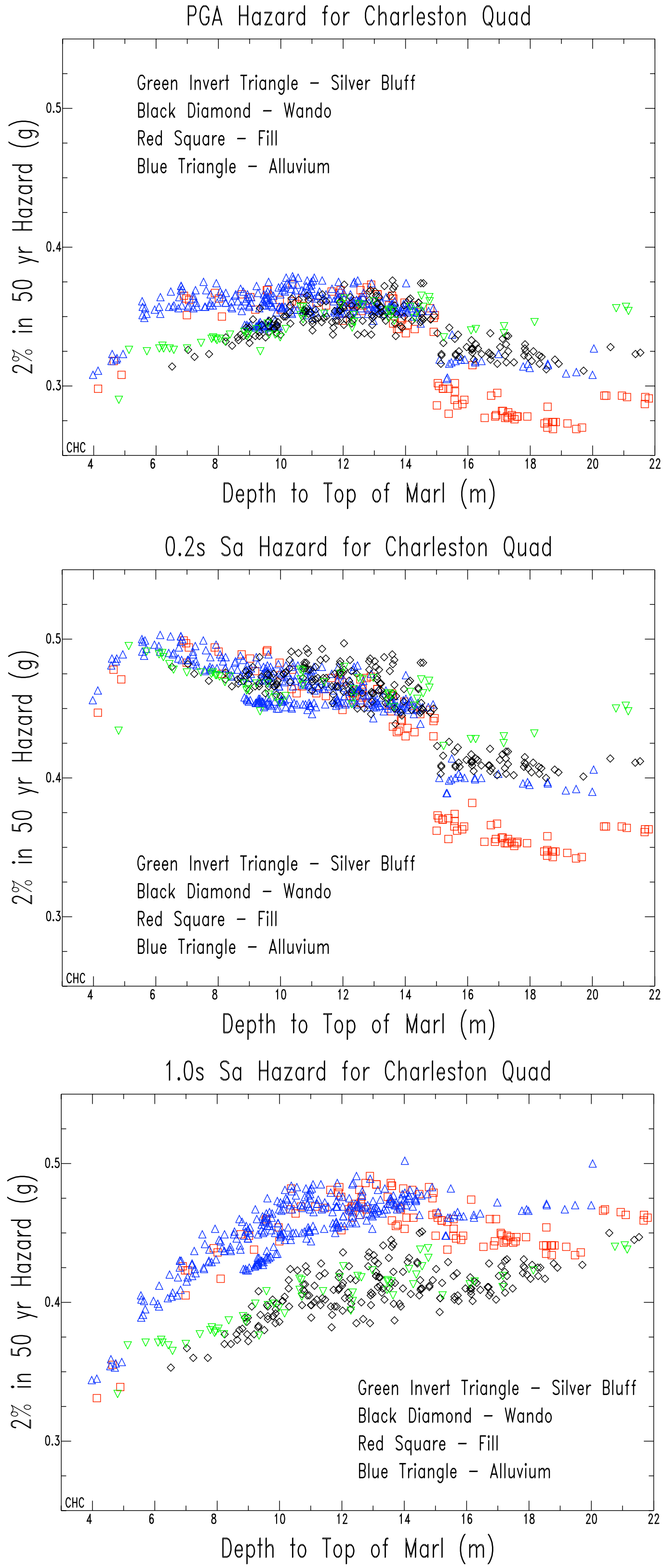


Figure 14: 2%-in-50yr seismic hazard in the Charleston quadrangle as a function of Quaternary soil thickness (depth to the top of Cooper Marl) and type for PGA (top), 0.2 s Sa (middle), and 1.0 s Sa (bottom).

Scenario Seismic Hazard Maps

We calculated scenario (deterministic) seismic hazard maps for M7.0 and M7.3 ruptures on a NNE trending strike-slip fault near Summerville, SC (see Figure 15). The fault ruptures were placed in the middle of the USGS narrow Charleston source zone corresponding to the zone of river anomalies passing through the Summerville area. We used the same median ground motion relations and weights as the 2008 USGS NSHMP probabilistic maps. Figure 16 presents the M7.0 scenario seismic hazard maps for PGA, 0.2 s Sa, and 1.0 s Sa. Ground motion hazard is ~0.2 g for PGA, ~0.25 g for 0.2 s Sa, and 0.3 to 0.4 g for 1.0 s Sa. Figure 17 shows the M7.3 scenario seismic hazard maps, which has slightly higher hazard but still ~0.2 g for PGA and ~0.25 g for 0.2 s Sa. For 1.0 s Sa the hazard ranges from 0.35 to 0.45 g.

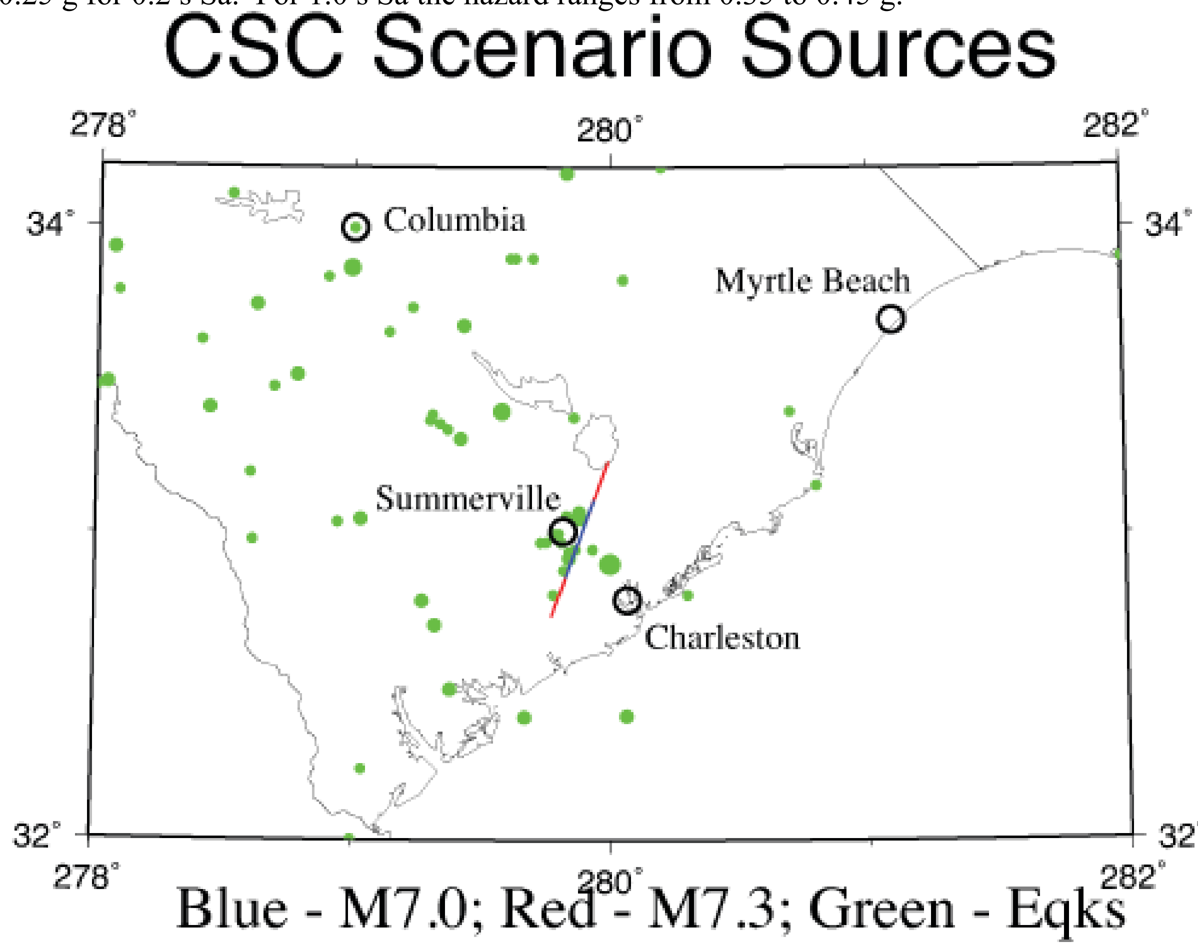


Figure 15: Location maps for M7.0 and M7.3 earthquake scenarios near Summerville, SC.

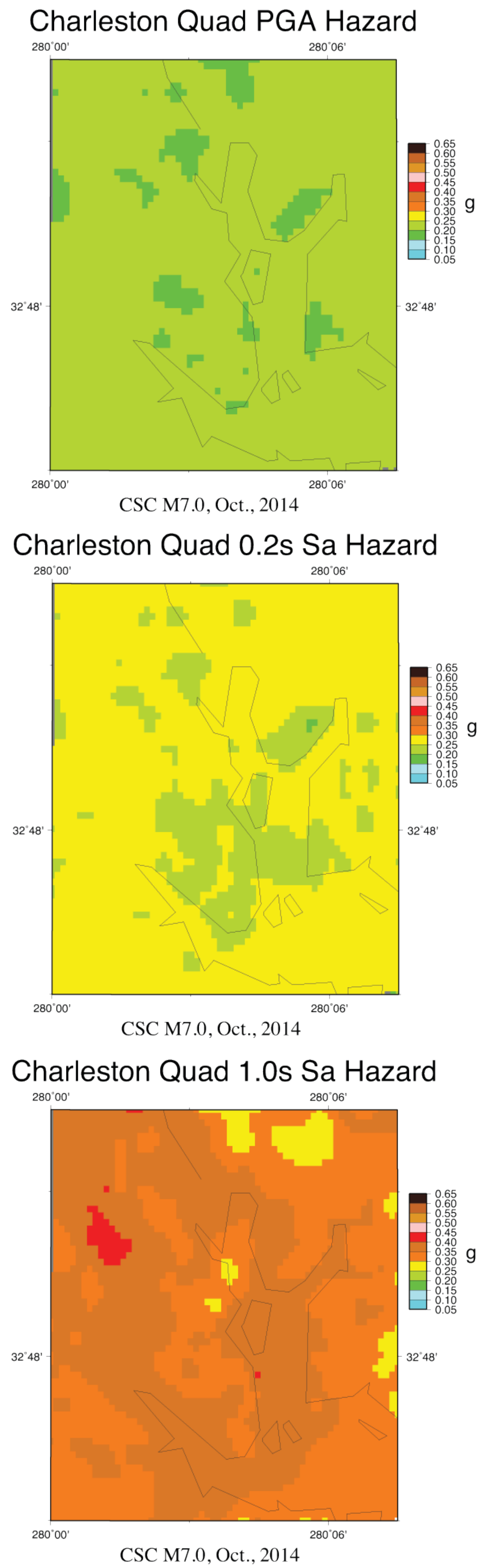


Figure 16: M7.0 earthquake near Summerville scenario seismic hazard maps for Charleston quadrangle for PGA (top), 0.2 s Sa (middle), and 1.0 s Sa (bottom).

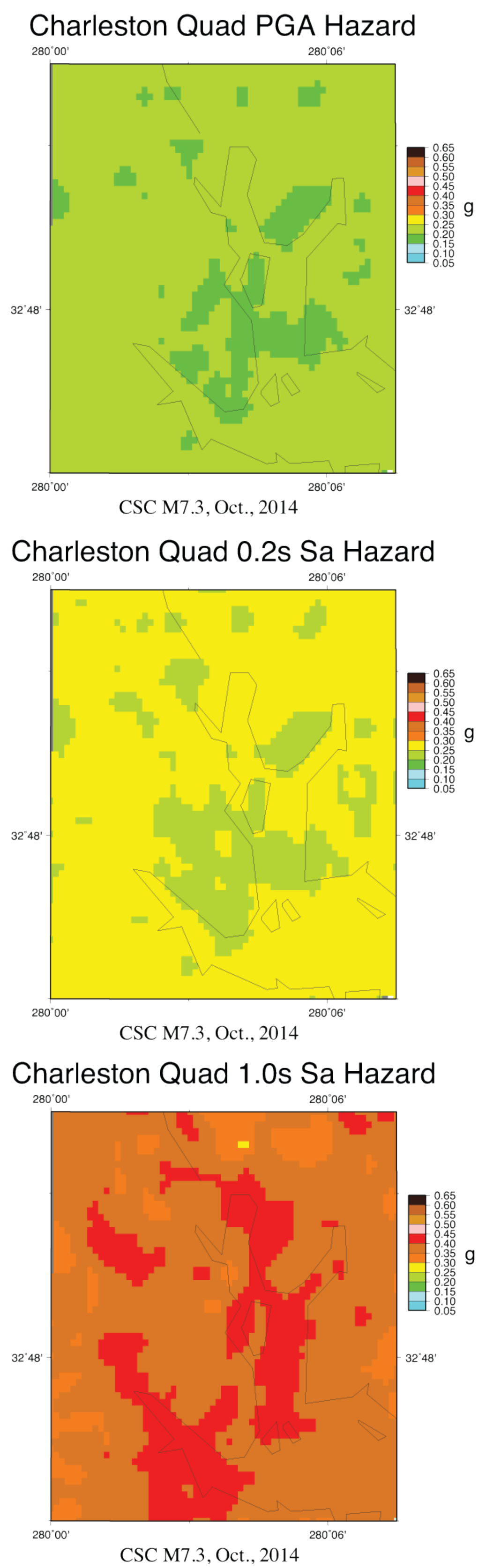


Figure C17: M7.3 earthquake scenario near Summerville equivalent to Figure 16.

Initial Liquefaction Urban Hazard Maps

We used the liquefaction probability curves of Heidari (2011) and water table depth distribution information from Simonson (2012) for generating liquefaction hazard maps for Liquefaction Potential Index (LPI) exceeding 5, which corresponds to moderate or worse liquefaction hazard. The probability of exceeding LPI 5 can be interpreted as the portion of the surface area at a site manifesting liquefaction features.

Heidari's (2011) liquefaction probability curves are a function of Quaternary soil thickness and depth to the water table. We implemented applying the Heidari curves as a function of the Quaternary soil thickness at a grid point. The Heidari curves are for Wando Formation, younger natural sediments, and artificial fill. We used the younger natural sediment Heidari curves for the Silver Bluff and alluvium surface geology types. Simonson (2012) indicates that the water table is predominantly between 1 and 2 m depth below the surface for all surface geology types. Following Simonson (2012) we used the 1 m Heidari curves for all surface geology types except the Wando and computed two alternative liquefaction hazard maps with the water table in the Wando at 1 and 2 m.

Liquefaction hazard maps were generated in a geographic information system (GIS) using a cookie cutter approach. Separate layers for each surface geology type, Quaternary soil thickness, and water table depth were generated over the whole quadrangle. Then in a GIS the appropriate portions were cut out of each layer and assembled into a liquefaction hazard map. Figure 4 is the surface geology map used to control the generation of the liquefaction hazard maps.

Scenario Liquefaction Hazard Maps

Using the median PGA seismic hazard maps of Figures 16 and 17 and the GIS-based approach outlined above, we generated liquefaction hazard maps for LPI>5 for both scenario earthquakes and for the alternative depth to water table in the Wando Formation of 1 and 2 m. Figure 18 presents the M7.0 scenario rupture shown in Figure 15 for both the 1m and 2m water table levels in the Wando Formation. On the Charleston peninsula in the middle of the Charleston quadrangle, the core area of the peninsula on Wando Formation with varying thickness shows lower liquefaction hazard than the areas near the edge of the peninsula on Silver Bluff, alluvium, and fill. The Wando 1m M7.0 scenario shows higher liquefaction hazard than the Wando 2m M7.0 scenario as expected. The core area of the peninsula liquefaction hazard varies from 30% to 50% probability of exceeding LPI 5 for the Wando 1m scenario, while varying from 10% to 30% in the Wando 2 m scenario. For the M7.0 scenario the edges of the Charleston peninsula show liquefaction hazard above 70% probability of exceeding LPI 5.

Figure 19 shows the same comparisons as in Figure 18 only for the M7.3 scenario. Because of the higher PGA values in the M7.3 scenario, the liquefaction hazard is generally higher than for the M7.0 scenario. For the M7.3 scenario, the core area of the Charleston peninsula has liquefaction hazard of 40% to 70% for the Wando 1 m water table alternative and 30% to 50% for the Wando 2 m water table alternative. The edges of the Charleston peninsula again show liquefaction above 70% for the M7.3 scenario.

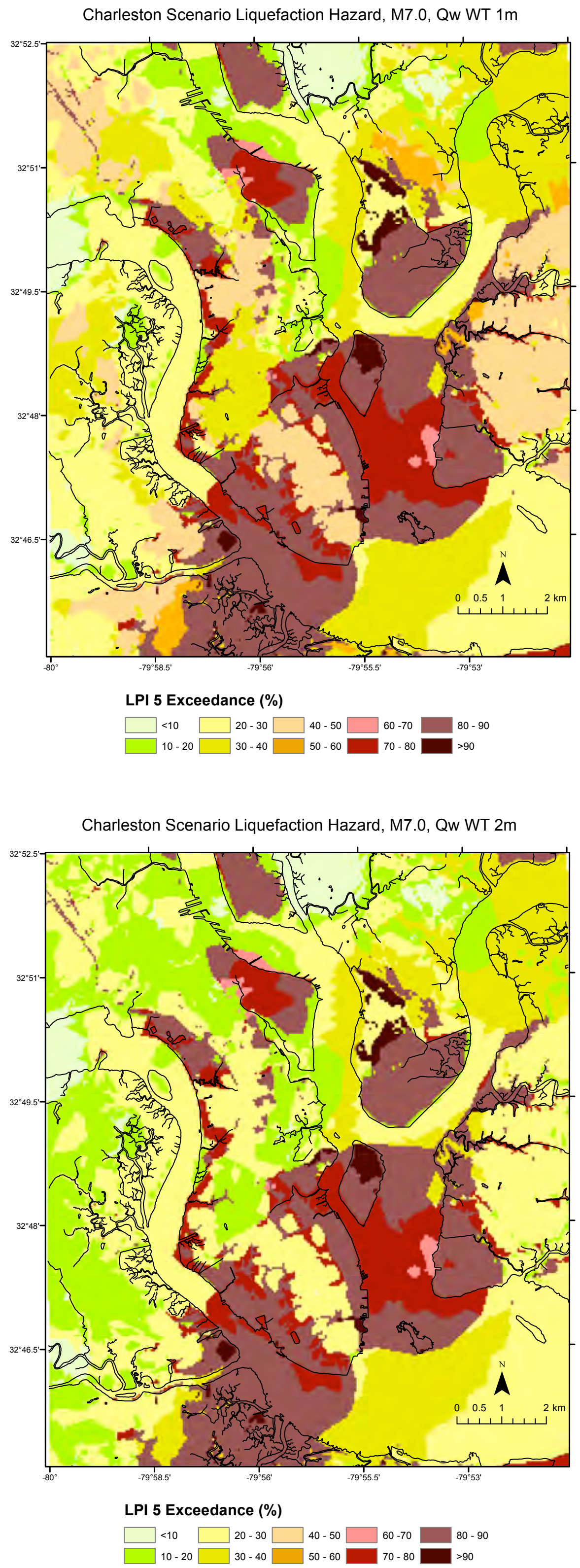


Figure 18: M7.0 liquefaction hazard maps for LPI>5 (moderate to severe liquefaction hazard) for 1m (top) and 2m (bottom) water table depth in the Wando Formation.

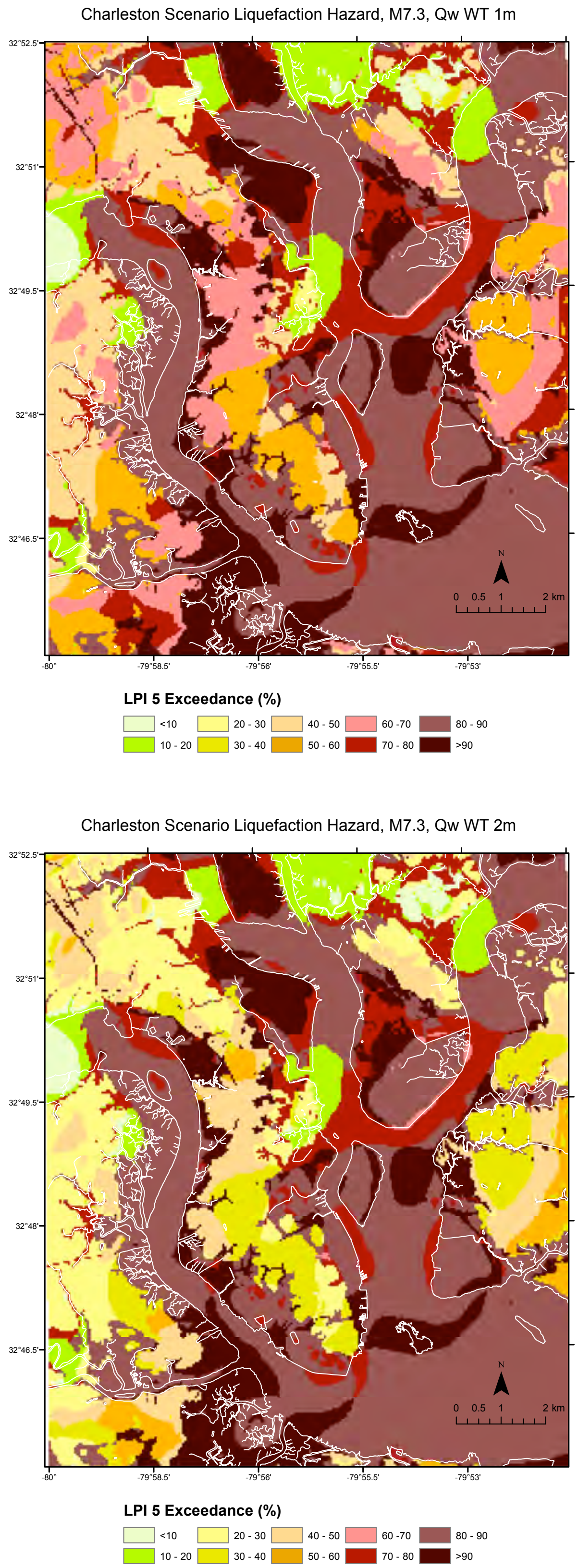


Figure 19: M7.3 scenario equivalent to Figure 18.

Simonson (2012) points out that in the 1886 Charleston earthquake there was little or no liquefaction in the Wando Formation areas of the Charleston quadrangle. This suggests that the M7.0 liquefaction hazard scenario with the Wando Formation water table at 2 m better fits the limited observations from the 1886 earthquake. To support the M7.0 being the more likely scenario for the 1886 earthquake, Cramer and Boyd (2014) indicate that the 1886 Charleston earthquake had a moment magnitude of 7.0 ± 0.3 at the 95% confidence level. However, keep in mind that the regional ground motion attenuation relations used in the 2014 NSHMP seismic hazard model update show reduced ground motions from the 2008 NSHMP model used in our initial urban hazard maps, so that the scenario hazard results for our initial scenario seismic and liquefaction hazard maps will be reduced using the 2014 NMSHMP model.

Probabilistic Liquefaction Hazard Maps

As a prelude to presenting the initial urban probabilistic liquefaction hazard maps for the Charleston quadrangle, we show the 2008 NSHMP Charleston seismic zone model alternatives in Figure 20. We show this to better explain the results. The 2008 Charleston seismic zone alternatives tend to spread the Charleston source over a large area relative to the scenario source zone of Figure 15. This will tend to spread and lower the probabilistic hazard more than occurs in the New Madrid seismic zone source, which still focuses the source alternatives close to the New Madrid fault system.

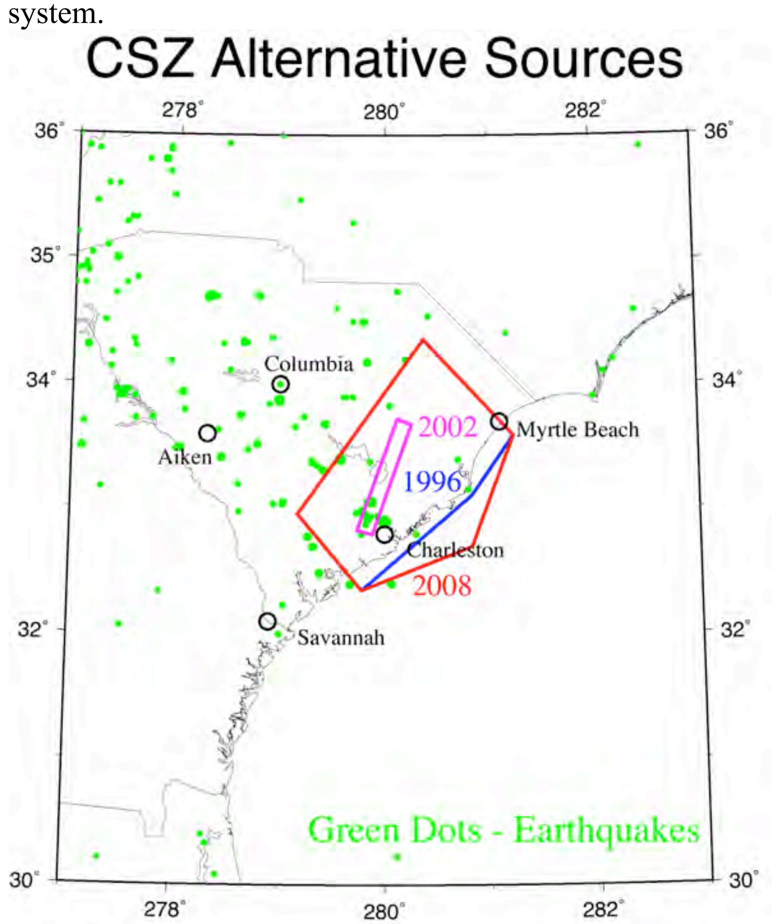
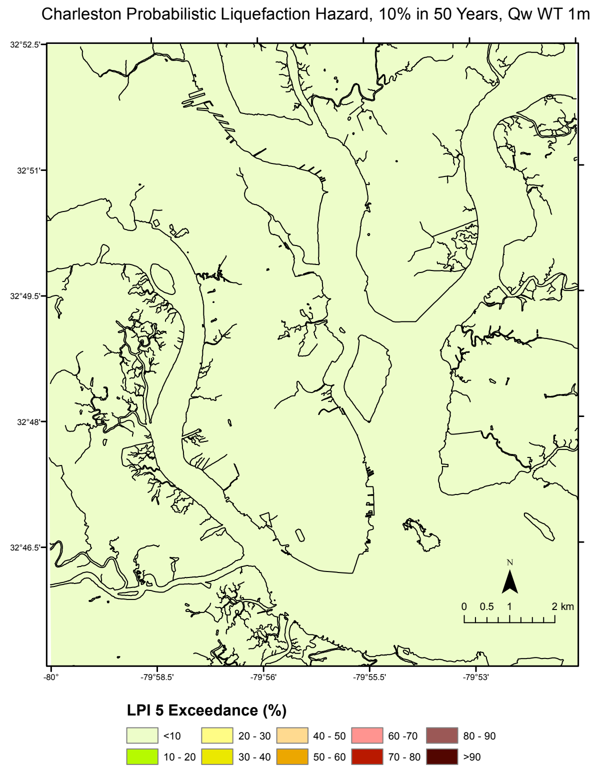


Figure C12: Maps of the three alternative Charleston seismic zones used in the 2008 USGS NSHMP model.

Figure 21 shows the resulting 10%-in-50yr liquefaction hazard maps for the alternative Wando Formation water levels of 1m and 2m. The liquefaction hazard is less than 10% probability of exceeding LPI 5. This is because the 10%-in-50yr seismic hazard is spread out over a larger area than the scenario M7.0 and M7.3 hazard as described above. The likelihood of strong liquefaction effects is only associated with the nearby large magnitude earthquakes in the hazard model and many of these large magnitude earthquakes are not as close as the Summerville scenario source causing the reduction in liquefaction hazard from what might be expected from a more concentrated, close-by source distribution. Thus these results are reasonable.

Figure 22 shows the 5%-in-50yr liquefaction hazard maps for the two Wando alternatives. For the core area of the Charleston peninsula (on the Wando Formation), the liquefaction hazard is less than 20% probability of exceeding LPI 5. On the edges of the peninsula the liquefaction hazard is 20% to 40%. This is still less than the M7.0 and M7.3 scenario liquefaction hazard maps, again due to the probabilistic source distribution, but less dramatically different. For a more concentrated, nearby source region with a 500-year return period (like New Madrid), the scenario and 5%-in-50yr hazard maps will be more similar.

Figure 23 shows the 2%-in-50yr liquefaction hazard maps similar to Figures 21 and 22. The liquefaction hazard for the core area of the peninsula is 40% to 60% for Wando 1m water level alternative and 20% to 40% for the Wando 2m water level alternative. The edge of the Charleston peninsula has a liquefaction hazard greater than 70% probability of exceeding LPI 5. The 2%-in-50yr liquefaction hazard is similar to the M7.3 scenario and somewhat higher than the M7.0 scenario.



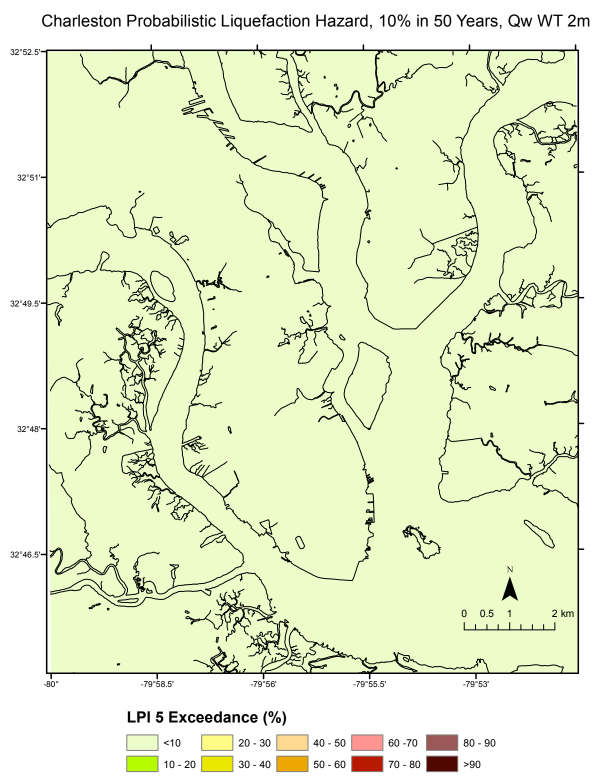
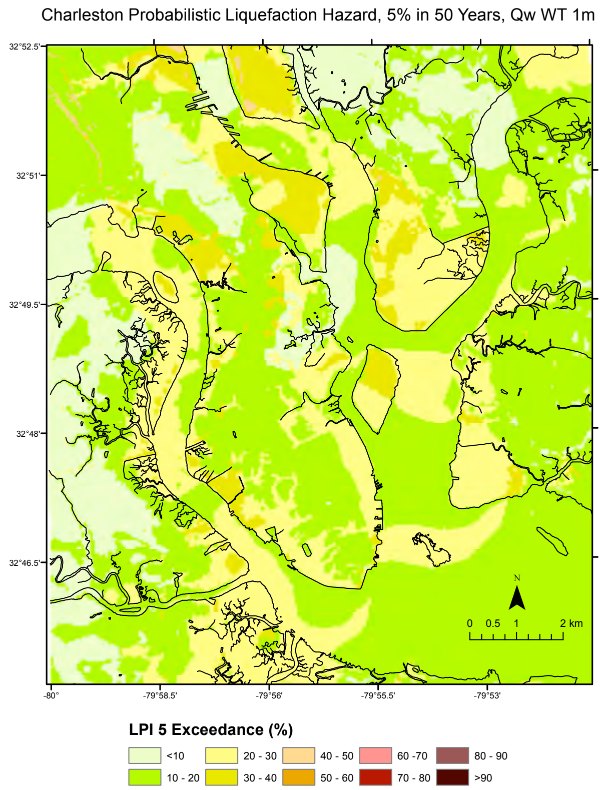


Figure 21: 10%-in-50yr liquefaction hazard maps for LPI>5 for the Charleston quadrangle with 1 m (top) and 2 m (bottom) water table depth for the Wando Formation.



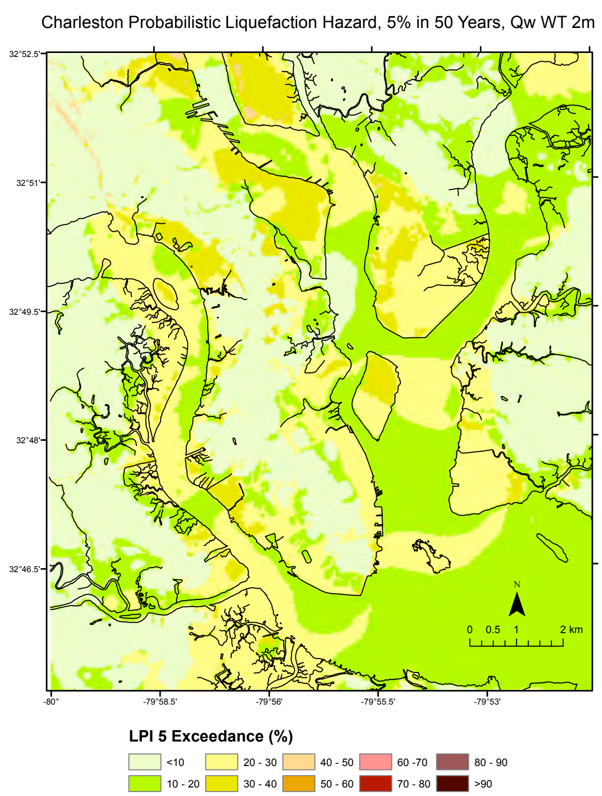
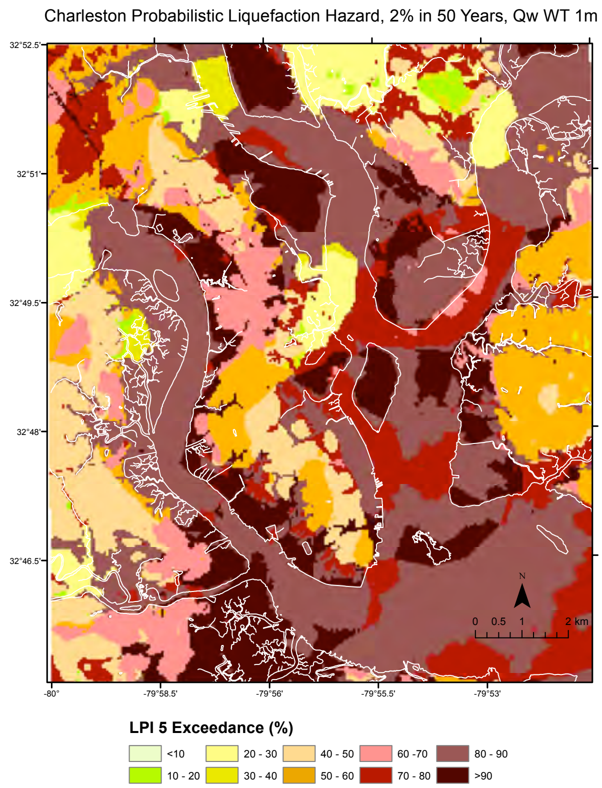


Figure 22: 5%-in-50yr liquefaction hazard maps for LPI>5 equivalent to Figure 21.



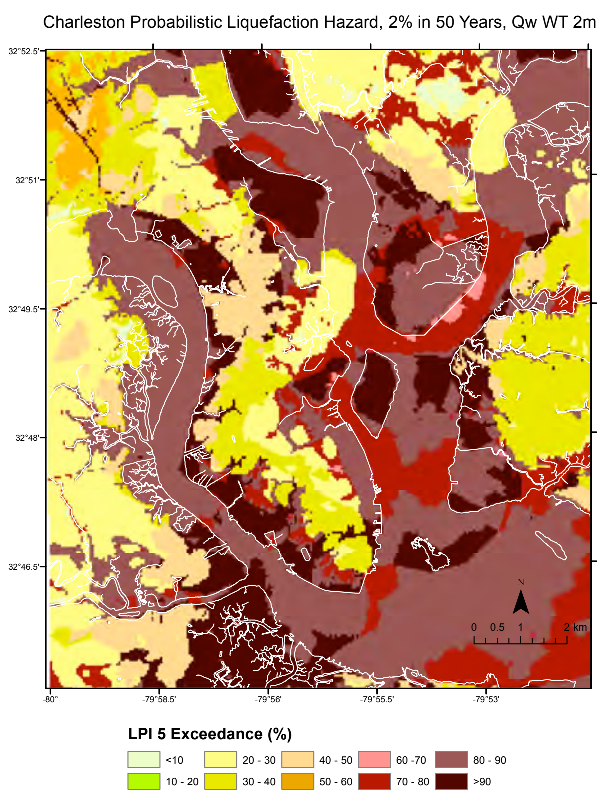


Figure C23: 2%-in-50yr liquefaction hazard maps for LPI>5 equivalent to Figure C21.

Remaining Issues

As a result of this pilot study, we have determined that there are three issues that remain related to urban hazard map generation to be addressed in continuing CAEHMP studies. The first is the issue whether the computationally efficient equivalent linear program (SHAKE91) provides sufficient accuracy above 0.5 g ground motions to provide an accurate enough picture of site amplification distributions expected for the Charleston, SC area. The question is not just nonlinearity but also dynamic pore-pressure effects on expected ground motions. Further testing with different nonlinear codes is needed to address this equivalent linear suitability question. Most geotechnical engineers have strong concerns about equivalent linear programs at such strong ground motion levels.

The second issue involves the computational resources needed for nonlinear programs, which have much longer run times than equivalent linear programs by two or three orders of magnitude. If nonlinear programs are more appropriate for the Charleston area due to the high ground motions expected, then the number of grid points to use in the urban hazard maps and the strategies to implement the nonlinear codes for urban hazard map generation need to be reviewed and improved to gain sufficient computational efficiency to make urban hazard map generation feasible with nonlinear codes.

The third issue is the lack of water table information and how it varies across the study area. The available information is generalized and averaged over a broad region. A more detailed depth to water table map would allow the adjustment of the liquefaction hazard estimates for known spatial variations in water table depth, just as we currently adjust the seismic and liquefaction hazard for variations in Quaternary soil thickness.

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Publications from this Research

No publications have resulted from this research as of this date. Future papers based on this work will be provided, as required, when publication occurs.

Appendix A – Workshop Agenda

<u>Charleston Urban Seismic Hazard Workshop</u>
March 5 – 6, 2014

Room 203, School of Science and Mathematics Building (SSMB)
202 Calhoun Street (corner of Calhoun and Coming Streets)
College of Charleston, Charleston, South Carolina
Nearest Parking
St Philip Street Garage (PG on the map attached to email)

<u>Agenda</u>

Wednesday, March 5, 2014

9-11 AM: Pre-Workshop Earthquake Walking Tour of Charleston

11 AM-Noon: Introductions & Role of Technical Working Group (TWG)
Ivan Wong (URS) – quick overview of 2000 HAZUS study
Rob Williams (USGS) – USGS thoughts on role of TWG

12-1 PM: Projected Growth of BCD Region / Elements of Urban Hazard Mapping
(Lunch will be provided)
Kathyrn Basha (BCD Council of Governments - projected growth of Berkeley-Charleston-Dorchester region
Chris Cramer (U Memphis) – elements of urban hazard mapping

1-4 PM: Status of Needed Technical Information
- Surface/Subsurface Geology/Geotechnical – Ron Andrus (Clemson)
- Vs Profiles/Measurements – Steven Jaume (College of Charleston)
- Earthquake Sources – Pradeep Talwani (U South Carolina)

4-5 PM: Status of Existing Seismic Hazard Model

Thursday, March 6, 2014

8-10 AM: Products – Chris Cramer (U Memphis)

10-11 AM: Outreach – Phyllis Steckel (EQ Insights)

11 AM-Noon: Data Management Issues – Norm Levine (College of Charleston)

Noon – 1 PM: Discussion of Scope of Project
(Lunch will be provided)

1-2 PM: Continued Scope Discussion with Action Items Review

2-4 PM: Post-Workshop Earthquake Walking Tour of Charleston

Appendix B – Attendees

Name	Institution
Ron Andrus	Clemson University
Kathryn Basha	Berkeley-Charleston-Dorchester Council of Governments
Craig Bennett, Jr.	Bennett Preservation Engineering PC
Erin Beutel	College of Charleston
Oliver Boyd	US Geological Survey
Scott Cave	Atlantic Business Continuity
Bill Clendenin, Jr.	South Carolina Geological Survey
Chris Cramer	University of Memphis
Greg Dreaper	US Army Corps of Engineers
Simon Ghanat	The Citadel
Steven Jaume	College of Charleston
Charles Kaufman	Dorchester County Emergency Management Division
Norman Levine	College of Charleston
Katie Luciano	South Carolina Geological Survey
Brett Maurer	Virginia Tech
Krystle Miner	US Army Corps of Engineers
Weichiang Peng	Clemson University
Thomas Pratt	US Geological Survey
Phyllis Steckel	Earthquake Insights LLC
Pradeep Talwani	University of South Carolina
Jim Tarter	Charleston County Emergency Management Division
Michael Ulmer	S&ME Inc
Michael Wadell	University of South Carolina
Rob Williams	US Geological Survey
Ivan Wong	URS

Appendix C – Scope Document

Proposed CAEHMP Two-Year Scope of Work 2015–2016

CAEHMP TWG

Major project efforts during 2015–2016, depending on funding, should be in six task areas: Community Model, Liquefaction Probability Analysis, Time History Database, Urban Hazard Maps, HAZUS Analysis, and Outreach. Work in these task areas should build on the 2014 pilot study funded under USGS NEHRP grant G14AP00024, which focuses on the Charleston and possibly Summerville 7 ½' quadrangles. The initial CAEHMP study area includes nine quadrangles: Summerville, Mount Holly, Stallsville, Ladson, North Charleston, Johns Island, Charleston, Fort Moultrie, and James Island.

Community Model:

Available data and information will be gathered into a community model that will be available for use by the scientists and engineers of the project and eventually be open for access by the general user community. Data layers needed include surface geology (already available from the S.C. Geological Survey), shear wave (Vs) measurements and profiles, geotechnical information (including soil/lithology types, layer boundaries with uncertainty, density with uncertainty, intrinsic damping, modulus and damping curves, etc.), depth to bedrock observations with uncertainties, and water table data. Currently available data and information will be compiled in the pilot study (e.g., Fairbanks et al. 2004; Andrus et al. 2006; Mohanan et al. 2006; Fairbanks et al. 2008; Hayati and Andrus 2008; Heidari and Andrus, 2010). Additional observations will be collected from the geotechnical consulting community, SCDOT, and other recommended sources during 2014–2015 in order to properly cover the initial study area with a 10 km buffer surrounding it.

Liquefaction Probability Analysis:

Some liquefaction probability curves based on surface geology have already been generated (Heidari and Andrus 2012). As part of the pilot study in 2014, existing liquefaction probability curves will be identified as part of the community model. Additional work is needed to improve the existing liquefaction probability curves and to extend them to all surface geologies. Appropriate SPT and CPT data will be compiled and analyzed in 2015 along with a review of the Charleston area liquefaction probability curves in light of the state-of-the-art in liquefaction probability curve generation, interpretation, and application. Then state-of-the-art liquefaction probability curves will be generated as needed by the CAEHMP for use in liquefaction urban hazard map generation in 2016.

Time History Database:

At the request of the engineering user community in the Charleston area, a time history database relevant to the CAEHMP study area will be developed in 2015. The target soil conditions for this time history database are those at the top of the Cooper Marl (clay). A state-of-the-art nonlinear soil response program, such as NOAH with dynamic pore-pressure effects (Bonilla, 2000; Bonilla et al., 2005), is most appropriate for this task. Representative soil profiles will be generated from the community model and appropriate hard rock time histories (such as Cramer, 2009) will be propagated from bedrock up to a Cooper Marl surface. Representative randomization of profile and soil properties will be included to generate an appropriate representative suite of Cooper Marl time histories for use by the engineering user community. Because of the proximity of major seismic sources to the Charleston area, a state-of-the-art nonlinear soil response program is necessary for generating the desired time history database. Additionally, records and site geology from the Christchurch, NZ sequence of earthquakes should be used to better calibrate the site response program NOAH and define the site response uncertainty for CAEHMP hazard analysis.

Urban Hazard Maps:

The generation of urban hazard maps, both seismic and liquefaction, depends on the results of developing both the community geological/geophysical/geotechnical model and liquefaction probability curves for the Charleston area. The currently funded pilot study does involve the generation of pilot urban hazard maps for one or two quadrangles in 2014, mainly as a guide to the TWG in evaluating the quality and completeness of information needed to generate urban hazard maps for the whole CAEHMP study area. Further, quality-control urban hazard map generation will be needed in 2015 as the community model and liquefaction probability curve tasks are completed and evaluated. Final CAEHMP urban hazard maps will be completed in 2016 for public release and use in a CAEHMP outreach workshop. Urban hazard maps will be generated using state-of-the-art approaches (Cramer, 2009, 2011; Cramer et al., 2004, 2006, 2008, 2012), nonlinear site response with the effects of dynamic pore-pressure changes (NOAH – Bonilla, 2000; Bonilla et al., 2005), and the 2014 USGS NSHMP source and attenuation models (Petersen et al., 2014). Urban hazard maps will be both probabilistic and scenario maps for seismic and liquefaction hazard.

HAZUS Analysis:

HAZUS analysis is dependent on the generation of the urban hazard maps for the CAEHMP study area. Much of the HAZUS analysis will be completed in 2016. But an initial pilot study analysis will be generated in 2014 for the pilot study quadrangles to evaluate the effectiveness of the community model. Also inventory improvements for the entire CAEHMP study area for use in HAZUS will be gathered and entered in 2015 ahead of the 2016 final analysis. Some HAZUS analysis will be needed in 2015 to assist with inventory quality control. Updated building and structure inventories will greatly improve the accuracy and applicability of the HAZUS analysis results. Although much of the HAZUS analysis will focus on selected earthquake scenarios, an analysis based on probabilistic seismic hazard maps will also be generated.

Outreach:

Interaction with the user community is very important for the CAEHMP. TWG conference calls and quarterly meetings are needed to gain scientific and engineering advice, guidance, and quality control. Continued interaction with the community, business, government, and engineers is critical to communicating the need for hazard mitigation efforts. This continuing interaction can be via presentations at meetings and conferences of many different disciplines, interactions with the media, and focused workshops. In 2016 an urban hazard map "rollout" workshop will be held to highlight the completion of the first set of CAEHMP urban hazard maps and to obtain further feedback from the user community. This "rollout" workshop could be coordinated with another professional meeting being held in the Charleston area or with an "Earthquakes: Means Business" conference in Charleston.

An additional aspect of outreach, is the making available of CAEHMP data and products via a public website. In Charleston, the Low Country Hazards Center (LCHC) at the College of Charleston is uniquely situated to assist with this outreach and data archiving task. Starting in 2014 and continuing through 2016, the LCHC can develop this aspect of public outreach, start archiving the community model, and serve via the web products generated by the CAEHMP.

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