

Measurements and Predictions of Vs30, Z1.0, and Z2.5 in Nevada

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Abstract

The Nevada Seismological Laboratory has posted a public database of Refraction Microtremor (ReMi) survey results of shear-wave velocity (V_s) versus depth in the Reno-area basin, and additional locations. Most of the V_s profiles were published previously in peer-reviewed journal articles. The database collects values of V_{s30} , $Z_{1.0}$, and $Z_{2.5}$ measured at 170 sites throughout the basin. V_{s30} is the time-averaged V_s between the surface and 30 m depth. $Z_{1.0}$ is the depth to the first occurrence of $V_s = 1.0$ km/s or greater, and $Z_{2.5}$ is the depth to $V_s = 2.5$ km/s. The database contains many more Reno-area sites with V_{s30} measurements that did not also have a $Z_{1.0}$ measurement; this report does not examine sites without $Z_{1.0}$ values.

All but a few sites have V_{s30} between 260 m/s and 760 m/s, with a majority in NEHRP hazard class C. Sites that are geologically on bedrock have unexpectedly low V_{s30} , <760 m/s. Intensive surveying of bedrock sites shows extreme lateral variability of V_{s30} as well as Z depths, with great variations over 20 m distances due to differential weathering of volcanic rocks. There appear to be no geological- or soil-mapping criteria able to predict V_{s30} in Nevada, consistent with previous work. Neither V_{s30} nor $Z_{1.0}$ can distinguish basin from bedrock sites in Nevada. Basin sites may well have faster V_{s30} measurements than nearby bedrock sites. Some bedrock sites have $Z_{1.0} > 0.1$ km, and some basin sites have $Z_{1.0} < 0.05$ km. In the Reno area, measured $Z_{1.0}$ varies from 0.015 km to 0.45 km; $Z_{2.5}$ varies from 0.1 km to 0.9 km. The ratio of $Z_{2.5}/Z_{1.0}$ is established with a minimum of 1.0, and with some sites exhibiting a ratio as high as 4.5. In 49 Las Vegas measurements along Las Vegas Blvd., $Z_{1.0}$ varies from 0.05 to 0.68 km; $Z_{2.5}$ measurements are not available. $Z_{1.0}$ is typically between 0.05 km and 0.11 km. Variations are likely due to highly variable occurrence of Tertiary caliche cementation.

Comparing the V_{s30} and Z values to gravity-derived basin depths (Z_g) correlates the depths and allows development of a practical approach for estimating $Z_{1.0}$ and $Z_{2.5}$ using ReMi or gravity data. Applying the models to gravity results for the Reno-area basin, Las Vegas Valley, and much of the Great Basin in Nevada and Eastern California produces maps of predicted $Z_{1.0}$ in Reno only, and $Z_{2.5}$ for wider areas, with reasonable results but large uncertainties. The V_{s30} and Z values provide a basis for estimating basin effects on earthquake shaking throughout Nevada and Eastern California using current Ground Motion Models (GMMs), an important consideration for seismic design and performance assessment of major civil infrastructure and lifelines throughout the region.

Introduction

In the United States, the time-averaged seismic shear-wave velocity between the surface and a depth of 30 m (V_{s30}) is a principal predictor of site effects on the intensity of earthquake shaking (BSSC, 2020). In searching for additional site-dependent factors affecting earthquake shaking, the depths at which the seismic shear-wave velocity property (V_s) reaches 1.0 km/s ($Z_{1.0}$) and 2.5 km/s ($Z_{2.5}$) appear to be related to shaking intensity and duration at sites in California and Japan (Campbell and Bozorgnia, 2013). These Z values correlate to the thicknesses of soft basin-fill clastic and volcanic sediments that amplify and prolong earthquake shaking, as demonstrated in Nevada by Flinchum et al. (2014).

Reducing the geographic bias toward California and Japan in Campbell and Bozorgnia's (2013) NGA West2 database of V_{s30} , $Z_{1.0}$, and $Z_{2.5}$ would allow development of better ground-motion prediction

equations (GMPEs) for a wider variety of locations. The Nevada Seismological Laboratory has for the past two decades been making surface-wave measurements at hundreds of sites in Nevada, and many hundreds more around the world. Vs30 as well as the Z values are found by conducting Refraction Microtremor (a.k.a., ReMi) seismic surface-wave surveys and producing velocity-versus-depth models. The Lab has collected together a new database of Vs measurements (Louie, 2020a), most previously published. We have added additional measurements appearing in research reports to sponsors, and some not otherwise published. This database is particularly rich in the relatively small Reno-area basin, where 170 sites all across the urban basin have Vs30 and Z1.0 measurements, and 107 of those sites have Z2.5 measurements. With these data, we can now examine the relationships between site velocity and depth properties, supplementing the NGA West2 database with abundant data from a new geography.

Most areas of Nevada, and the USA, lack detailed shear-wave measurements. This is particularly true of rapidly urbanizing exurbs on the fringes of growing metropolises such as Reno or Las Vegas. Since 1970, Nevada's population has grown from under half a million to over three million. Estimates of basin-fill thicknesses derived from gravity data are more likely to exist, with much more of the state, and country, covered by gravity surveys than by near-surface (i.e., depths of geotechnical interest) seismic surveys. A technique to predict Z1.0 and Z2.5 from gravity data would be helpful for identifying regions that warrant basin-specific seismic surveys for engineering use on critical projects (BSSC, 2020; Campbell and Bozorgnia, 2013).

Methods

ReMi measurements of Vs– Vs30 together with Z1.0, and often Z2.5, were measured at 170 locations in Reno, Nevada, within the large new database of Refraction Microtremor (ReMi) seismic survey results (Louie, 2020a). The database contains hundreds more Reno-area sites with Vs30 measurements that did not also have a Z1.0 measurement; this report does not examine sites without Z1.0 values. The great majority of the shear-wave velocity versus depth profiles we used in this analysis have been published previously in peer-reviewed journals (Scott et al., 2004; Pancha et al., 2006; Pancha et al., 2017b) or in publicly available research reports to the US Geological Survey (Louie et al., 2009; Pancha et al., 2011; Pancha and Pullammanappallil, 2014; Pullammanappallil, 2016).

The ReMi measurement method collects microtremor noise along a linear array of vertical geophones, transforms the time-distance seismic records to the slowness-frequency domain, interprets the fundamental-mode Rayleigh phase-velocity dispersion curve at the lowest possible apparent velocity at each frequency, and then forward-models a 1D Vs-versus-depth profile to fit the picked dispersion (Louie, 2001). Available images of ReMi slowness-frequency spectra and picked dispersion-curve data are actively being added to the Louie (2020a) database. Vs30 values are computed for each site from the modeled shear-wave velocity-versus-depth profiles using the time-averaging method given in the NEHRP provisions of the Building Code (BSSC, 2020). In typical commercial geotechnical application, the array of 12, 4.5 Hz geophones is 88-110 m long, dispersion picks can be made between 4 and 25 Hz, and the depth of velocity constraint is derived from the dispersion-modeling process and usually 30-100 m.

Depth of velocity constraint– The maximum depth of velocity constraint is individually analyzed and modeled for every Vs profile in the Louie (2020a) database. In Reno, various practices of ReMi surveying have resulted in depths of constraint varying from 14 m to over 2.5 km. While most database entries have a depth of constraint between 50 and 100 m, Scott et al. (2004) used 300 m arrays to measure 54 Vs soundings in Reno with depths of constraint exceeding 100 m, exceeding 300 m at faster sites. Pancha and Pullammanappallil (2014), Pullammanappallil (2016), and Pancha et al. (2017b) made 106

“deep ReMi” soundings in the Reno basin in the Louie (2020a) database, using arrays up to 6 km long resulting in dispersion picks at frequencies as low as 0.3 Hz, yielding depths of constraint of 1.0 km or more. In Las Vegas, Nevada, Scott et al. (2006) made 49 soundings in Las Vegas with 300 m array lengths, resulting in depths of constraint exceeding 100 m, in some cases exceeding 300 m.

Measuring Z1.0 and Z2.5– For each shear-wave velocity versus depth profile in the database, if the V_s value reached at least 80% of 1.0 km/s (0.80 km/s) at some depth, that depth was assigned to Z1.0 for that measurement site. Likewise, if the V_s reached at least 80% of 2.5 km/s (2.0 km/s) at some depth, then Z2.5 was interpreted to be at that depth. ReMi surveys can have $\pm 30\%$ velocity uncertainty for individual layer velocities in the V_s versus depth model, particularly for the deeper layers (Louie, 2001). The uncertainty in time-averaged velocities such as V_{s30} is less; $\pm 15\%$. Thus, we interpret a Z value at the depth where the modeled velocity only reaches 80% of the threshold velocity. As a result, Z values reported in the Louie (2020a) database may be regarded statistically as minimum Z values. If the V_s in a site’s profile never reaches at least 80% of the threshold velocity, then the Z value is noted to be greater than the depth of constraint posted for that profile.

Sites without Z1.0 measurements not discussed here– The interpreted Z1.0 and Z2.5 values and the measurement locations were loaded into MATLAB for analysis along with the V_{s30} reported for each measurement. Table 1 lists all 170 V_{s30} , Z1.0, and Z2.5 data points for Reno. Only results from surface-wave measurements in Reno where seismic shear-wave velocities reached at least 80% of 1.0 km/s and 2.5 km/s were used, numbering 170 for Z1.0 and 107 for Z2.5 in total.

Finding nearby gravity data for basin thickness– Using the Abbott and Louie (2000) gravity dataset, the nearest gravity measurement of basin-fill thickness Z_g to each V_s measurement was found. As discussed by Langenheim et al. (2001) and Pancha et al. (2017b), a basin-thickness measure derived from gravity analyses ought to correlate with Z2.5 in most sedimentary basins. Since the grid spacing of Abbott and Louie (2000) was 0.4 km, any V_s measurement that was more than 0.5 km away from a Z_g (gravity basin-depth value) value of >0.01 km had its Z_g value set to zero. Out of 170 measurements, 23 had their Z_g reduced to zero for Z1.0, and only one measurement had its Z_g reduced to zero for Z2.5.

Cross-plots– Figure 1 shows a cross-plot of the V_{s30} value against Z1.0 value measured at each of 170 sites in the Reno-area basin. Figure 2 shows the cross-plot of the measured Z1.0 against Z2.5 for 107 of these Reno sites. Graphs of Z1.0 versus Z_g and Z2.5 versus Z_g for Reno appear in Figures 3 through 10. We created approximate empirical models to predict Z1.0 and Z2.5 from Z_g , in MATLAB using its curve-fitting tool. Exponential and linear models with coefficient confidence intervals of 95% were derived using least-squares fits to the data in Figures 3 through 10. Two models were determined to predict Z1.0, and two for Z2.5, an exponential and linear model each. The models, and their minimum and maximum bounds from the coefficient intervals, were plotted over the cross-plots, and they fit the data reasonably (Figures 3-6).

Additional gravity data sets– The nearest-neighbor fits to determine Z_g for each seismic station were also performed with other Reno gravity data sets: a gravity data set surveyed for Reno by Washoe County (Widmer, 2005; Widmer et al., 2007; Cashman et al., 2012); and a US Geological Survey gravity inversion for clastic and volcanic basin-fill thickness across the entire Basin and Range by Saltus and Jachens (1995). Since the grid spacing for Saltus and Jachens (1995) is 2 km, any V_s measurement more than 1.5 km from a gravity measurement had its Z_g from these region-wide data set to zero. There were only eight V_s measurement sites for Z1.0 that had their Widmer Z_g reduced to zero. All four models were applied to cross-plots of Z1.0 or Z2.5, for the Abbott, Widmer, and Jachens data all on one graph

(Figures 7-10). The exponential models for both Z1.0 and Z2.5 from Z_g fit the Reno data most favorably. Extrapolating the models derived for Reno allows at least Z2.5 to be roughly estimated elsewhere in the Great Basin, where gravity results can provide a Z_g value.

Results and Discussion

Observations on the measured Vs profiles— Out of the 170 Vs30 measurements in Reno that appear in Table 1 and Figure 1, only a few have Vs30 values below 260 m/s. These measurements appear here only by virtue of being at a site having a measured value of Z1.0. There are many additional measurements of Vs30 in the Reno area appearing in the Louie (2020a) database that show values below 260 m/s. These are not discussed here because they did not also provide a measurement of Z1.0. Their depth of constraint was evidently less than Z1.0. This is true of most commercial ReMi measurements in soft sediments, which typically have a depth of constraint of only 50 m. As an extreme example, series of ReMi measurements in a hot-spring marsh in the Black Rock Desert north of Reno reliably exhibited Vs30 values as low as 81 m/s (and depths of constraint of only 30 m).

Perhaps more of a surprise is that only one of the Reno-area ReMi measurements in Table 1 and Figure 1 shows a Vs30 value above 760 m/s. This Vs30 value is the boundary between NEHRP Class C “Very dense soil and soft rock” and Class B “Rock”. Table 1 shows many more “rock site” measurements, having very small Z1.0 depths, but all of these sites show measured Vs30 values below 760 m/s. As Pancha et al. (2007) discussed, all of the seismic recording stations in the Reno area that should be rock sites, have Vs30 values measured to be less than 760 m/s.

Pancha et al. (2007) investigated among others the seismic recording station at “SWTP” on the east side of the Reno-area basin, frequently used as a rock site when investigating basin amplification of earthquake shaking in Reno. Their SWTP measurement in Table 1 has a Vs30 of 731 m/s and a Z1.0 of 119 m. The follow-up SWTP-RS measurement by Pancha et al. (2011), also in Table 1, has a Z1.0 of just 7 m, but a Vs30 of 552 m/s. This measurement is just 20 m away from the Pancha et al. (2007) measurement, on colluvium over hard andesite. The very different Vs30 and Z1.0 measurements reflect the extremely rapid spatial variation of shear-wave velocity in the deeply weathered volcanic-rock masses that form the bedrock in much of the Reno area. Despite this extreme spatial variation, rock sites in the Reno area reliably show Vs30 values below 760 m/s, in the NEHRP C site class (Figure 1).

The highest Vs30 value in Table 1 and Figure 1 is from the VSTA2 site in north Reno, also on the local Miocene andesite bedrock. With a Z1.0 of 26 m, it has a Vs30 of 833 m/s. Pancha et al. (2008) investigated an adjacent site (RFNV in Table 1) extensively with ReMi recordings. As a follow-up study, the Nevada Seismological Lab deployed a series of ReMi arrays within 200 m of RFNV in close proximity to each other, and at different orientations. These results appear in Table 1 as the VSTA measurements. The VSTA arrays are all very close to each other. As at SWTP, the RFNV and VSTA measurements reflect the extreme lateral velocity variations in the heavily weathered bedrock typical of the Reno area.

Z1.0–Vs30, and Z2.5 characteristics— In Figure 1, one would expect Z1.0 to be negatively correlated with Vs30. As the average shear-wave velocity to 30 m depth increases, one might expect the depth to a velocity of 1.0 km/s to become shallower. Figure 1 does appear to show such a negative trend, a line sloping steeply down to the right. But this trend appears as an upper limit for the points in the plot. Below this limit, Z1.0 can take almost any value, even less than 30 m.

One such extreme example is a site on the eastern margin of the Reno-area basin, published by Scott et al. (2004). At this site on Cleanwater Way where it crosses Steamboat Creek, Vs = 166 m/s between the

marsh at the surface down to 8 m depth, increases to 276 m/s, and then at only 15 m depth sees the 940 m/s andesite bedrock, the basin edge. Thus, this site (131-145-284.txt in Table 1 and the Louie, 2020a database) yields a measured Vs30 of 330 m/s and a Z1.0 of 0.015 km. At this low Vs30 value, Figure 1 suggests the down-to-the-right sloping trend of the Z1.0 upper limit would yield a maximum Z1.0 of 0.5 km.

Figure 2, the cross-plot of Z1.0 against Z2.5, suggests a more predictable relationship between the two depth measurements in Reno. Reno is underlain by several small, shallow sub-basins, each several kilometers wide, and generally 0.5 km to 1.2 km deep at maximum (Abbott and Louie, 2000). Pancha et al. (2017b) demonstrate with deep ReMi measurements that the basin floor, even at >0.5 km depth, may dip at greater than 45°. With basins this small, and basin-floor dips this steep, Figure 2 should not be expected to yield a sensible average or standard deviation for Z1.0 or Z2.5. The Z depths will vary greatly according to a site's exact location, and its underlying geologic structure. Given that Reno is an area of rapid, active tectonics, with on-going mountain uplift and basin subsidence, the high degree of aleatory variance in the Z values is expected.

Figure 2 together with the curve fits on Figures 3 through 10, do suggest reliable minimum values for the Z1.0 and Z2.5 basin depths across both rock and basin sites in the Reno area. The fits suggest that Z1.0 will be greater than 0.11 km, to 98% confidence. As well, Z2.5 will be greater than 0.25 km, to 98% confidence. These Z minima speak to the depth of weathering effects on the volcanic bedrock in the Reno area. Many measurements show that rock sites generally have a low-velocity surface layer. The most prominent difference between velocities within the Reno-area basin, and outside it on the local bedrock, appears to be simply the thickness of the low-velocity (<760 m/s) surface layer. The low-velocity surface layer is simply thicker in the basins.

Flinchum et al. (2014) made use of this observation in their physics-based computational modeling of ground motions in Las Vegas, Nevada due to the 1992 M5.7 Little Skull Mtn. earthquake. They assembled their 3D community velocity model from southern Nevada Vs30 data in the Louie (2020a) database, plus the 10,722 Vs30 measurements in the Clark County Parcel Map (Pancha et al., 2017a). Flinchum et al. (2014) made regional averages of Vs30 measurements taken in basins, and on rock. Given the averages, where they did not have a measurement, they applied a default rock-site Vs30 of 760 m/s. For basin sites not near a measurement, they applied a default Vs30 of 500 m/s. Similar default Vs30 values could well apply to the Reno area. These default values emphasize the observation that basins and bedrock in Nevada do not have much difference in velocity near the surface.

In Figure 1 there does not appear to be any clear criterion in the Reno area to separate basin from bedrock sites on the basis of their Vs30 value. Weathering and the resulting extreme velocity heterogeneity affect both Vs30 and Z1.0 measurements taken at sites that geologically should be rock sites. The geological location of a measurement, within the basin or on bedrock, does not appear to allow any prediction of Vs30 or Z1.0 in the Reno area. The darker points in Figure 1 come from the Las Vegas basin (Scott et al., 2006), and appear at the end of Table 1. In Las Vegas the gravity analyses of Langenheim et al. (1998; 2001) suggest fast, dense bedrock at depths Zg greater than 0.3 km. These arguably basin locations span the whole range of Vs30 shown in Figure 1 but show apparently “bedrock” Z1.0 values, only as deep as 0.1 km. This phenomenon arises from an abundance of calcified Tertiary soil B horizons, buried throughout western Las Vegas Valley at depths up to 200 m (Scott et al., 2006).

There are a number of measurements of Z1.0 equal to Z2.5 in Table 1 and Figure 2. Many parts of the Reno-area basin are Quaternary in age. Having low-velocity Quaternary sediments directly overlying

high-velocity Miocene volcanics, or Mesozoic granites and metavolcanics, is geologically reasonable even at depths approaching 0.5 km (Pancha et al., 2017b). Above those points on the plot having equal Z1.0 and Z2.5, many of the 107 measurements suggest a ratio of Z2.5/Z1.0 of about 2.5. The maximum Z2.5/Z1.0 ratio appears in Figure 2 to be just under 4.0.

Extrapolating Z measurements to unmeasured areas— Given the Louie (2020a) database of shear-wave velocity measurements, we seek a method of extrapolating Z1.0 and Z2.5 to areas without velocity measurements, from other data on basin depths. The Zg values derived from gravity analyses of basin thicknesses are available just about everywhere in Nevada and Eastern California. Reno and Las Vegas have specific analyses that provide much detail on their basin geometries. From the gravity results, it is possible to make general predictions of Z1.0 and Z2.5 depth values anywhere in the region. These predictions may aid the National Seismic Hazard Mapping Project and allow engineers to consider Z1.0 and Z2.5 in assessing earthquake-shaking hazards.

The curve fits on Figures 3 through 10 suggest exponential models to predict Z1.0 and Z2.5 from gravity basin depths Zg. The models are:

$$Z_{1.0} = a_1 \cdot \exp(b_1 \cdot Z_g), \quad a_1 = 0.1408 [0.1145, 0.1671], \quad b_1 = 0.5484 [0.2582, 0.8387]. \quad (\text{Eq. 1})$$

$$Z_{2.5} = a_2 \cdot \exp(b_2 \cdot Z_g), \quad a_2 = 0.3042 [0.2518, 0.3565], \quad b_2 = 0.5478 [0.3090, 0.7867]. \quad (\text{Eq. 2})$$

The models both had very low R² values, 0.09 for the Z1.0 model and 0.15 for the Z2.5 model. The 95% confidence limits on the Z1.0 and Z2.5 predictions are quite wide, reflecting the low correlations. These poor correlations are a result of the extreme, rapid lateral variations in shear-wave velocities at Reno sites. One impact of the resulting poor accuracy in predicting Z1.0 and Z2.5 from Zg is that any seismic-hazard map product using these predictions should not be used to assess the hazard at any specific sensitive site. Instead, specific geological, geophysical, and geotechnical investigations are needed to characterize Z1.0 and Z2.5 properly. However, the poorly predicted Z1.0 and Z2.5 values are accompanied by an uncertainty, between the 95% confidence bounds, that is quite useful. Greater hazard uncertainty implicitly raises hazard levels (Campbell and Bozorgnia, 2013). The predicted Z values and their uncertainties can provide useful regional assessments of hazard, and identify areas where the hazards and their uncertainties are likely to be larger.

The Z2.5 model was applied to the Langenheim et al. (1998, 2001) Zg dataset for Las Vegas. The deepest predicted basin depth using the average coefficients was not deeper than the maximum Zg basin depth of 4.8 km, so the model does not give wholly unacceptable values for basin depth, even at the other end of Nevada from the data in Reno. Z1.0 and Z2.5 were calculated for the Jachens, Abbott, and Langenheim Zg data sets. The percent error between the basin depth calculated from the average coefficients and the depth calculated from the minimizing coefficients get quite high. The modal error for Z1.0 and Z2.5 in the product derived from Abbott and Louie (2000) was 21% and 17% respectively. The maximum errors were 42% and 38% respectively. The maximum errors for the Saltus and Jachens (1995) and the Langenheim et al. (1998, 2001) products are much higher, 100% and 81% respectively.

Figure 11 shows that the Z1.0 model may not apply outside of the Reno basin, since the Z1.0 model consistently overestimated Z1.0 for Las Vegas Valley. These relatively shallow Z1.0 measurements in Las Vegas likely come from buried Neogene soils cemented with caliche (Scott et al., 2006). As a result, Z1.0 is not published for any Zg data outside of the Reno basin. Z2.5 data are published despite there being no direct Z2.5 measurements from Scott et al. (2006) for Las Vegas Valley in the Louie (2020a) seismic shear-wave database.

Data File Format

Assembled measurements of Vs30, Z1.0, and Z2.5 in Reno are given in Table 1. Predicted Z1.0 and Z2.5 results are contained within three plain text data files in the .zip file accompanying this report. Within each text file, Z1.0 and Z2.5 have been estimated for each location listed in the corresponding gravity data set of Zg values: Abbott and Louie (2000) for Reno; Langenheim et al. (1998, 2001) for Las Vegas; and Saltus and Jachens (1995) for the entire Basin and Range. Each location's estimate is one row in the text file.

The columns of the text files, from left to right, are: latitude, degrees WGS84; longitude, degrees WGS84; Zg, km; Z1.0min, km; Z1.0, km; Z1.0max, km; Z2.5min, km; Z2.5, km; Z2.5max, km; Z1.0error, percent; and Z2.5error, percent. The latitude and longitude are converted directly from the published gravity databases, and the Zg values are taken directly from their published results. The Z values are determined as described above from the best-fit coefficients in Equations 1 and 2, estimated from the Zg values. Z values are not forced to any nearby measured Z values that appear in Table 1. The minimum Z values result from the application of the 95% confidence minimum coefficients in Equations 1 and 2; the maximum Z values result from the application of the 95% confidence maximum coefficients in Equations 1 and 2. The Z errors are the percentages resulting from subtracting the minimum Z from the best-fit Z, and then dividing by the best-fit Z.

Users should bear in mind that the Z1.0 estimates are not thought to be valid outside the Reno-area basin. All Z1.0 predictions in the Langenheim and Saltus files, outside the Reno area, should be ignored. Geologically, Z2.5 is thought to coincide with the depth to the floor of Tertiary and Quaternary basins filled with either clastic or volcanic sediments having slower velocity and lesser density, atop denser and faster Mesozoic basement. Figures 12 through 15 present maps of Z1.0 and Z2.5 for Reno, and of Z2.5 for Las Vegas and all of Nevada and Eastern California, respectively. The accompanying .zip file has the map images, as well as a KML file allowing Google Earth to show the Z maps. Map data are supplied also as JRG Packs for plotting and spatial analysis with the free JRG/Viewmat software tools (Louie, 2020b).

Conclusions

The new Louie (2020a) database of ReMi seismic shear-wave velocity soundings (available at <https://sites.google.com/view/vs-profile-archive>) adds significant data to national earthquake-hazard mapping efforts. It is intended as well for use by geoscience researchers and engineering practitioners in Nevada. Out of hundreds of Vs measurement sites in the database for Nevada and Eastern California, this report examines only those sites in Reno and Las Vegas yielding both Vs30 and Z1.0 measurements. There are 170 such sites in Reno and 49 in Las Vegas, with 107 of them also having a Z2.5 measurement. Table 1 summarizes the location, Vs30, Z1.0, and Z2.5 measurements, along with gravity-derived Zg estimates for the 219 sites. Most of these data have been previously published.

Examination of the Vs30 measurements at the 219 sites reveals the following characteristics:

- All but a few sites have Vs30 between 260 m/s and 760 m/s.
- A majority of the sites have Vs30 measurements in NEHRP hazard class C.
- Sites that are geologically on bedrock have unexpectedly low Vs30, with almost all considerably lower than 760 m/s.
- Bedrock sites investigated with intensive surveying programs (e.g., Pancha et al., 2008) show extreme lateral variability of Vs30, with velocity variations of greater than 20% observed over distances of tens of meters.

- There appear to be no geological- or soil-mapping criteria able to predict Vs30 in Nevada, as discovered by Scott et al. (2004) for Reno, by Scott et al. (2006) and Pancha et al. (2017a) for Las Vegas.
- Vs30 does not distinguish basin from bedrock sites in Nevada. Basin sites may well have faster Vs30 measurements than nearby bedrock sites.

Measurements of Z1.0 and Z2.5 at these 219 Nevada sites reveal the following characteristics:

- Some bedrock sites have Z1.0 measurements exceeding 0.1 km.
- Some basin sites have Z1.0 measurements of less than 0.05 km.
- It is not possible to definitively separate geologically defined basin sites from bedrock sites on the basis of their measured Z1.0 depth.
- Bedrock sites investigated with intensive surveying programs (e.g., Pancha et al., 2008) show extreme lateral variability of Z depths, with great variations observed over distances of tens of meters.
- In the Reno area, measured Z1.0 varies from 0.015 km to 0.45 km; Z2.5 varies from 0.1 km to 0.9 km.
- Reno-area basin Z2.5 measurements vary according to geologic structure.
- Reno-area bedrock Z measurements vary greatly over short distances due to differential weathering of volcanic rocks.
- In 49 Las Vegas measurements along Las Vegas Blvd., Z1.0 varies from 0.05 to 0.68 km; Z2.5 measurements are not available.
- In the 49 Las Vegas measurements, Z1.0 is typically between 0.05 km and 0.11 km. Variations are likely due to highly variable occurrence of Tertiary caliche cementation.
- In the Reno area, the ratio of Z2.5 over Z1.0 measurements at a site is established with a minimum of 1.0, and with some sites exhibiting a ratio as high as 4.5.

We undertook an effort to produce Z1.0 and Z2.5 maps predicting Z depths across Nevada and Eastern California. We were able to determine models to predict Z1.0 and Z2.5 from gravity-derived thicknesses Zg with some constraints on uncertainties at 95% confidence. The percent errors are lower in Reno, higher in Las Vegas, and much higher in the Saltus and Jachens (1995) dataset, but still reasonable. Correlation coefficients are very poor, suggesting that the predicted Z maps not be used at individual sites, but only for broad regional assessments.

The models were determined by fitting the seismic data in Reno, Nevada, where the maximum measured Z2.5 is 1.2 km. It is a leap to apply them to Las Vegas data with Zg values as deep as 4.8 km, and an even bigger leap to apply it to the Saltus and Jachens (1995) dataset that spans much of the Great Basin down to the Arizona-Mexico border, with many calderas and Neogene basins having Zg exceeding 8 km. Still, the uncertainties accompanying the Z predictions will be useful in hazard studies.

These estimated Z maps may still prove a useful tool in seismic hazard studies, by pinpointing areas of interest for further measurements. More seismic surveys to determine Z1.0 and Z2.5 are needed in the future to provide additional constraints, and to refine these models. Efforts are underway to measure additional Z2.5 depths in Reno, and to integrate the geophysical and geological views of the basin. Given the current 2.3 million population of Las Vegas, and the city's economic importance to the State of Nevada, immediate efforts should begin to measure Z2.5 throughout the basin.

Declaration of Potential Perceived Conflict of Interest

The ReMi technology is owned by the University of Nevada, and licensed exclusively to [Optim Earth, Inc.](#) Optim pays royalties to the University based on their commercial revenues from ReMi. As inventor of the technology, under University policy John Louie personally receives a share of those royalties.

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Disclaimers

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Any measurements and observations made within approximately 50 km of Yucca Mountain, Nevada, and specifically any locations or magnitudes of seismic events, are preliminary information only. Please contact the [archive of the Yucca Mountain Project Technical Library](#) to obtain quality-assured technical data relating to seismic activity, ground conditions, or other natural phenomena near Yucca Mountain.

The information included in these documents is intended to improve earthquake preparedness; however, it does not guarantee the safety of an individual structure or facility. The State of Nevada does not assume liability for any injury, death, or property damage that occurs in connection with an earthquake.

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Figures

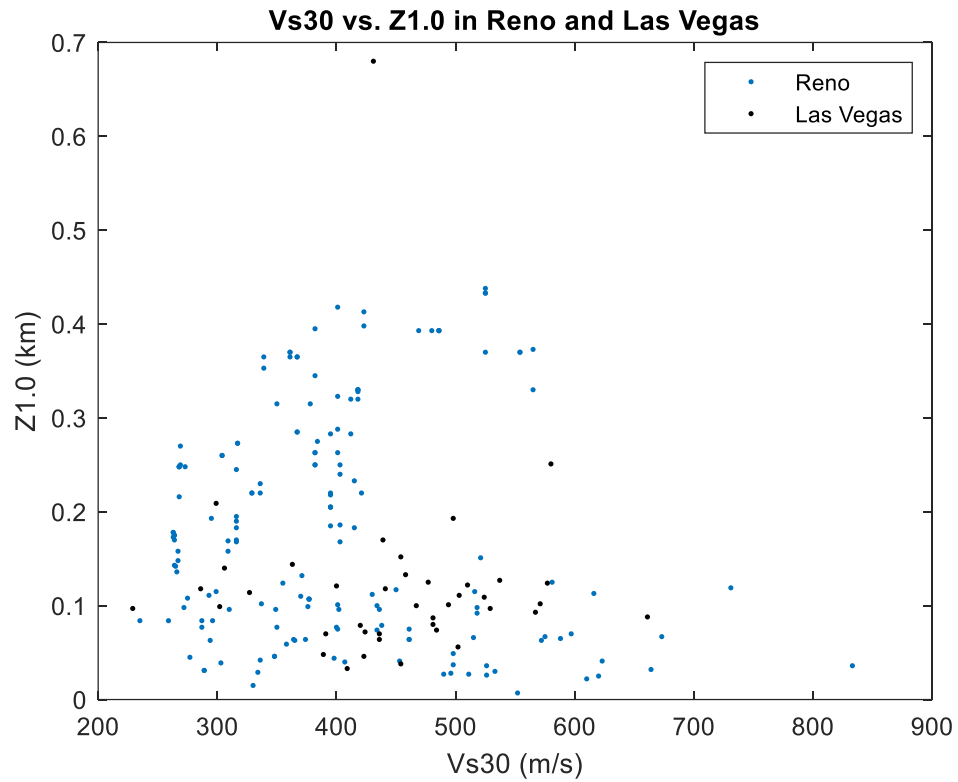


Figure 1: Graph of Z1.0 vs. Vs30 from Reno and Las Vegas seismic shear-wave data.

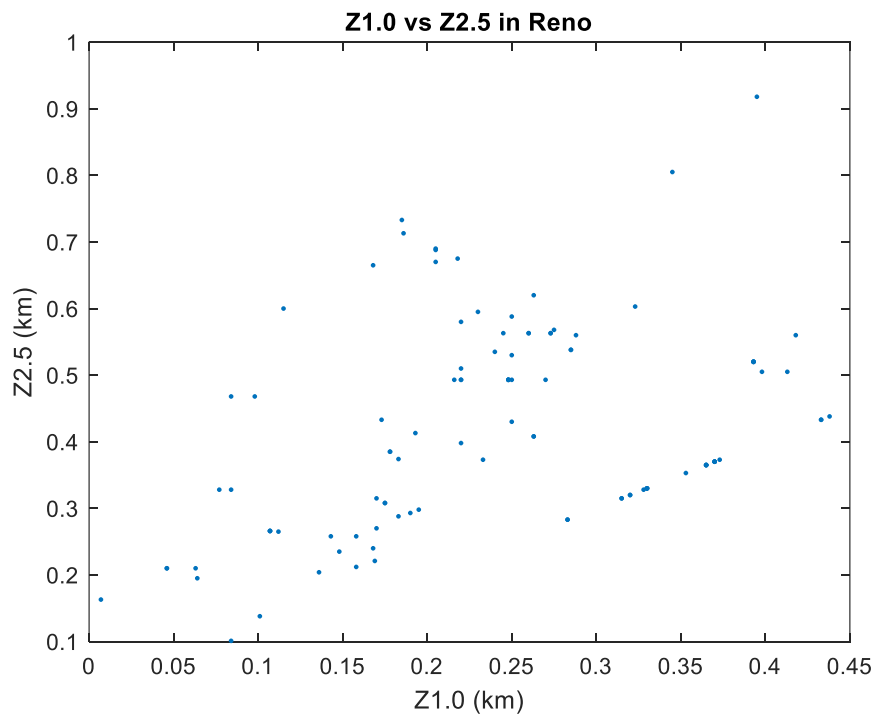


Figure 2: Graph of Z2.5 vs. Z1.0 from Reno seismic shear-wave data.

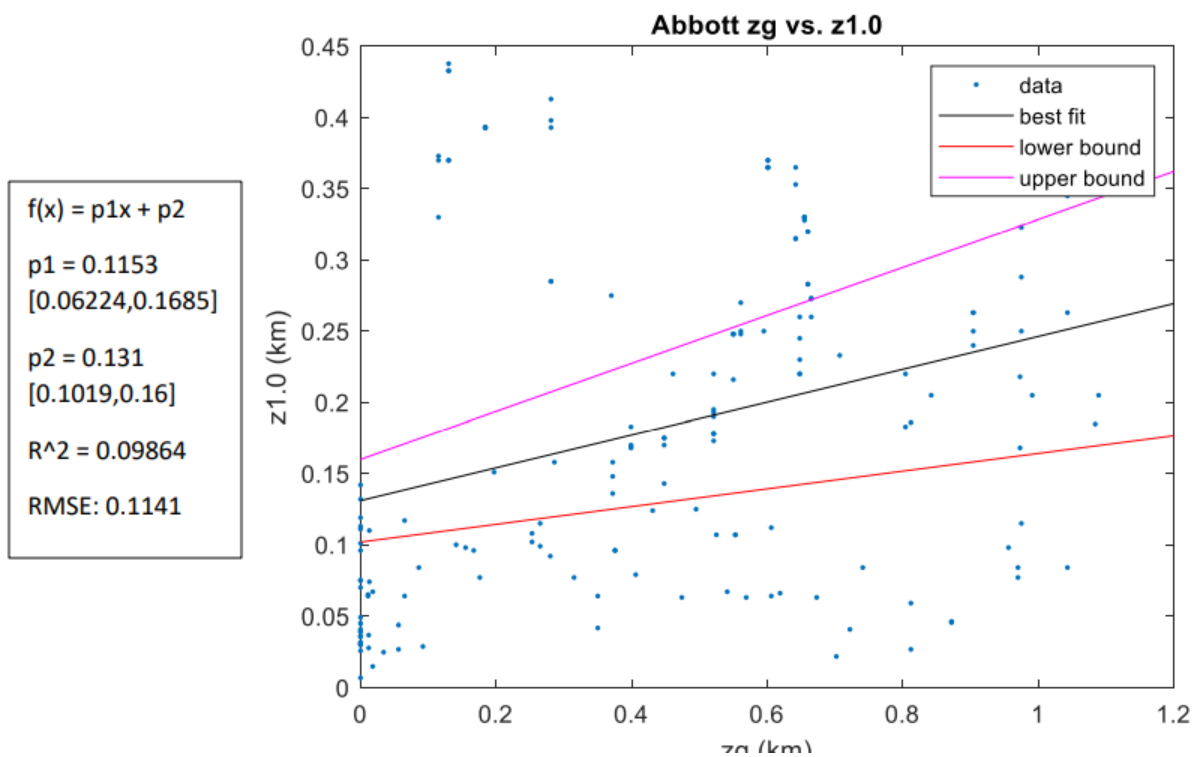


Figure 3: Linear model of Z1.0 vs. Zg in Reno

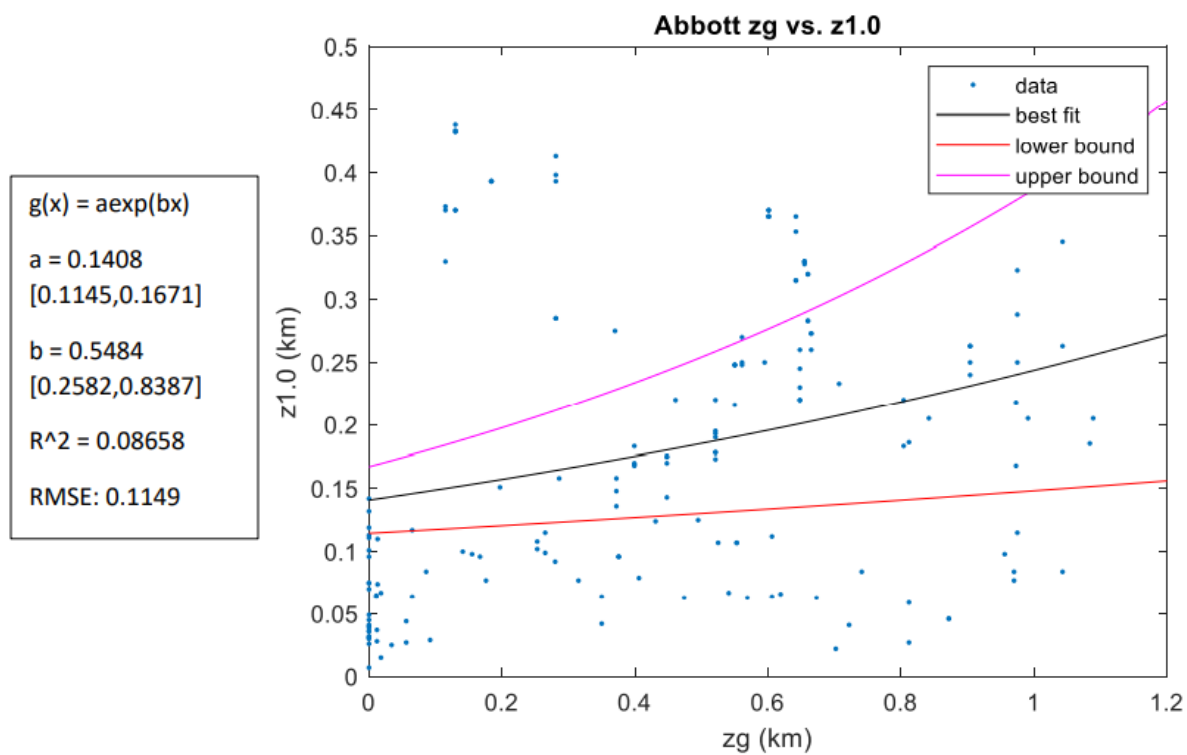


Figure 4: Exponential model of Z1.0 vs. Zg in Reno

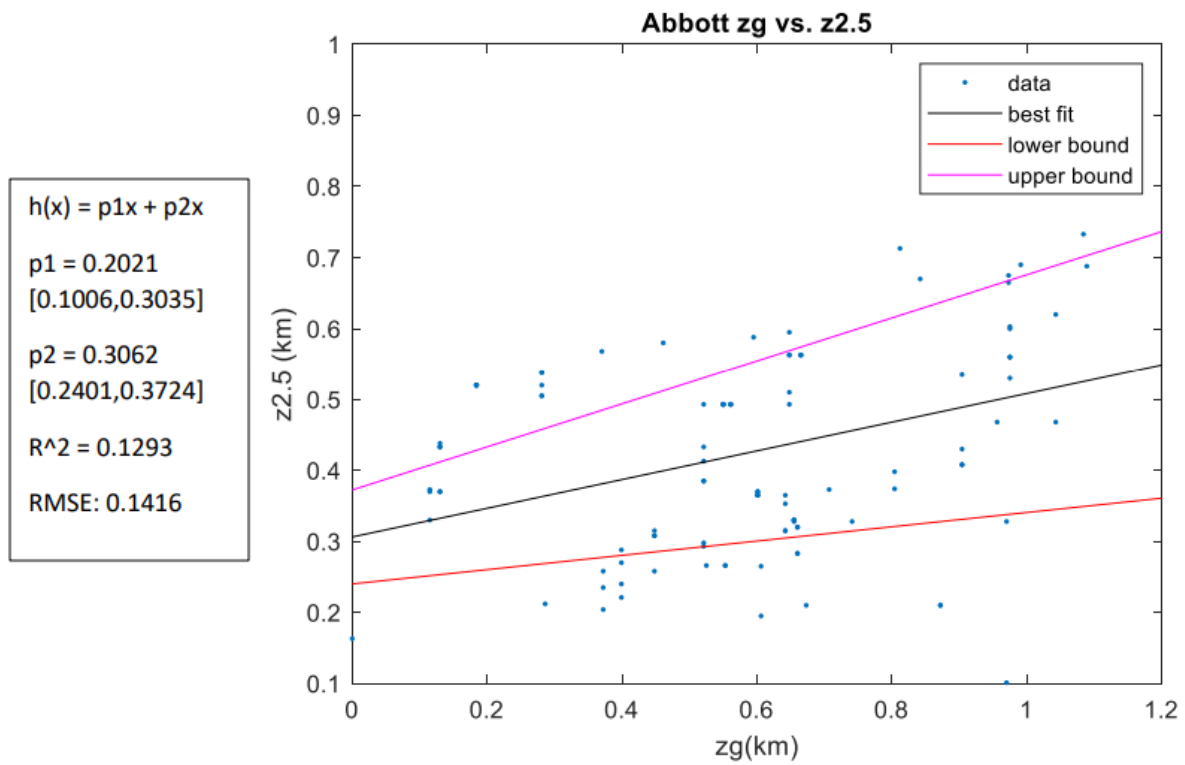


Figure 5: Linear model of Z2.5 vs. Zg in Reno

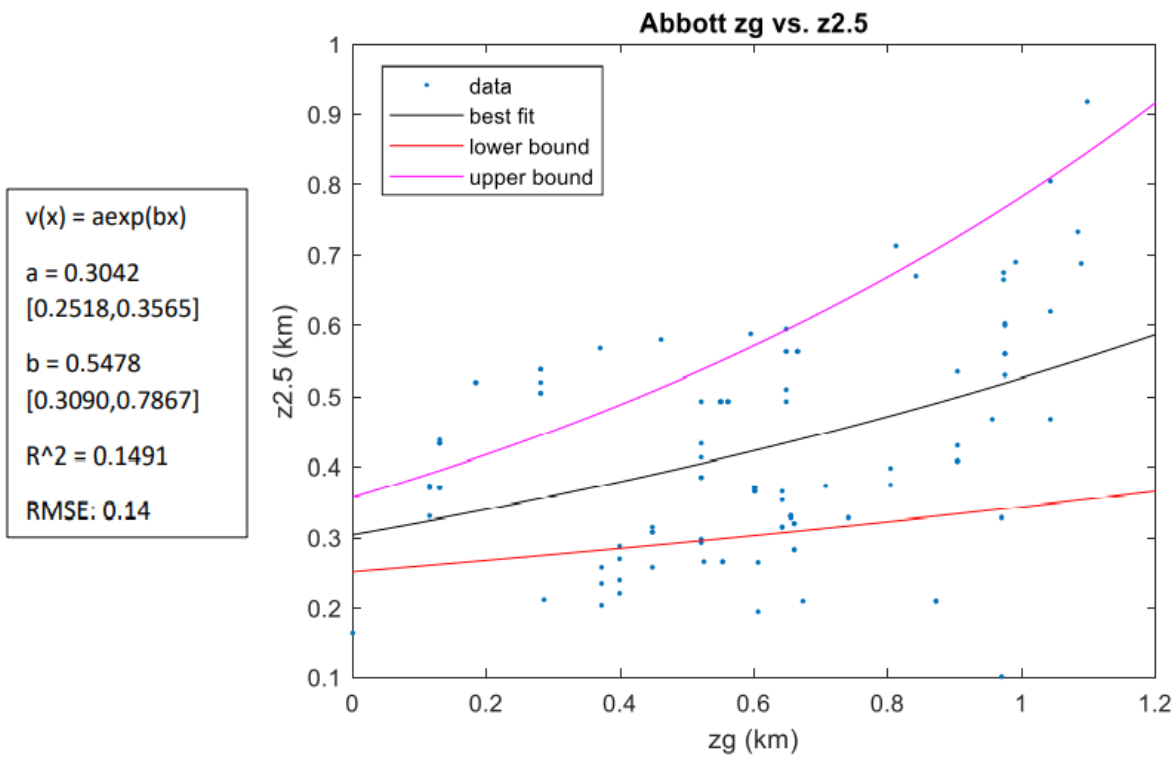


Figure 6: Exponential model of Z2.5 vs. Zg in Reno

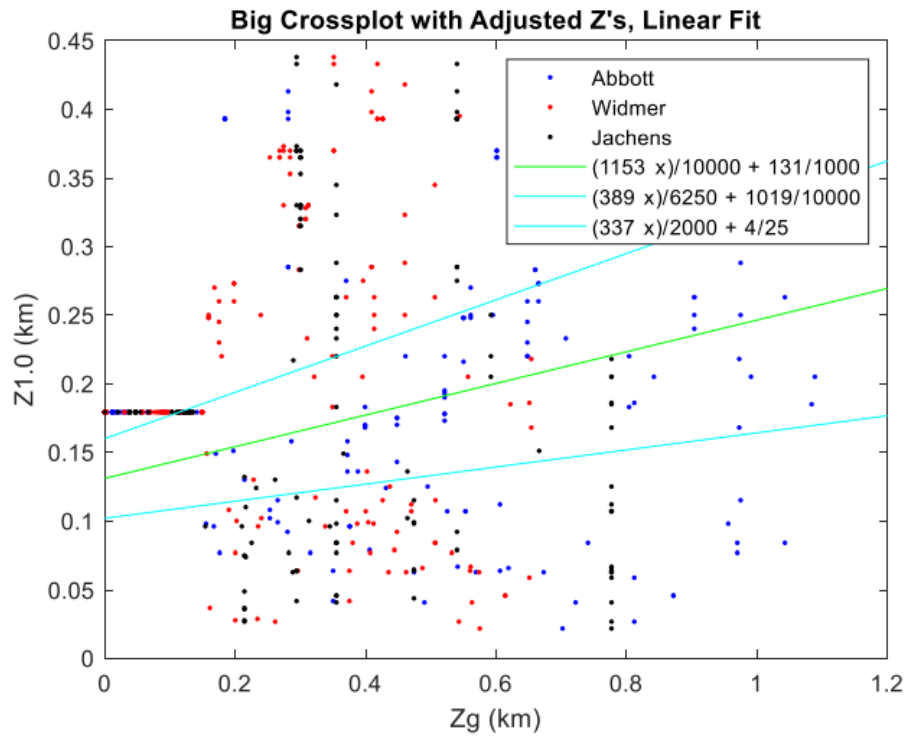


Figure 7: All Reno shear-wave data plotted against all Reno gravity data. Linear model of Z1.0.

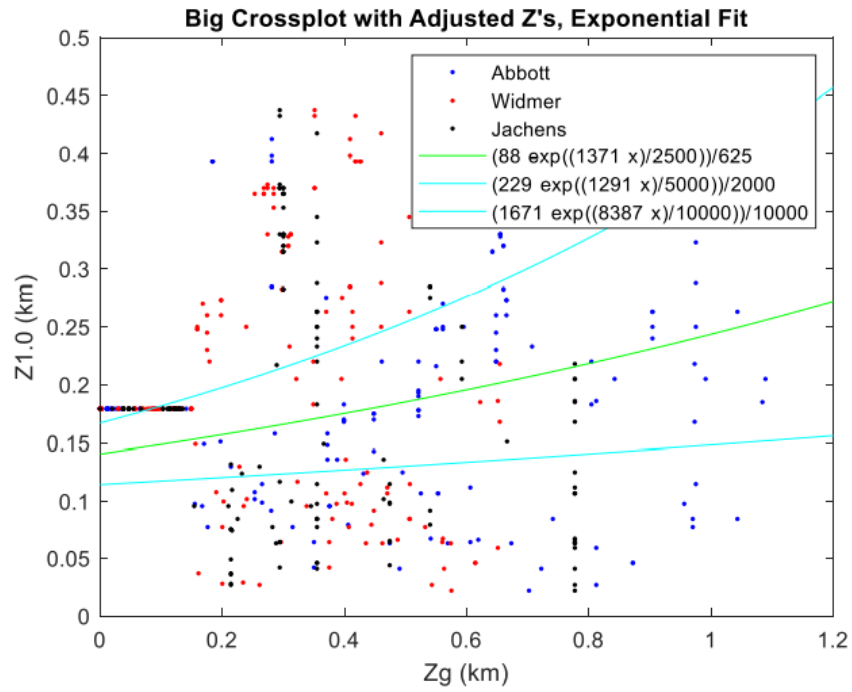


Figure 8: All Reno shear-wave data plotted against all Reno gravity data. Exponential model of Z1.0.

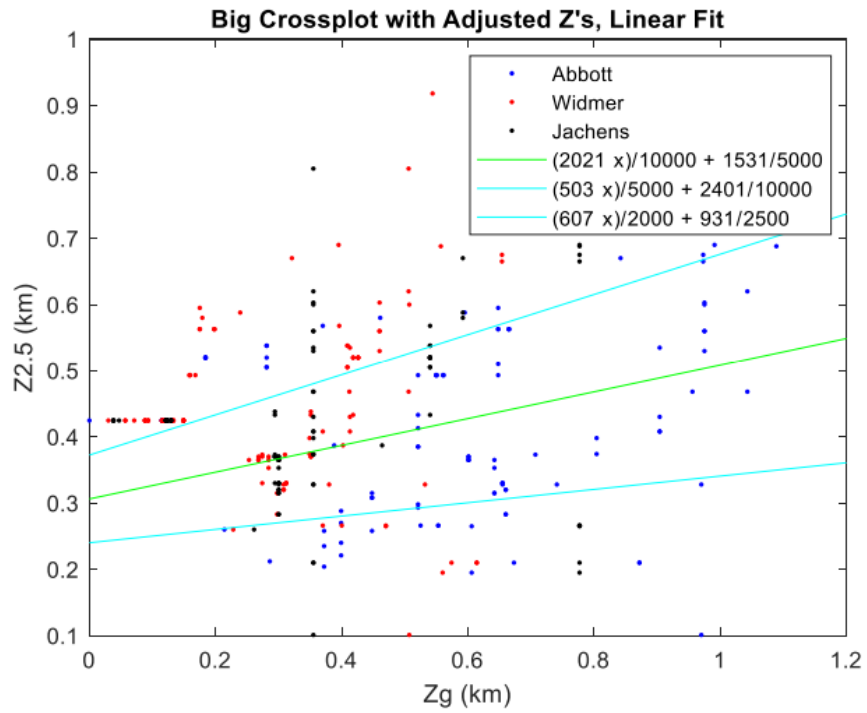


Figure 9: All Reno shear-wave data plotted against all Reno gravity data. Linear model of Z2.5.

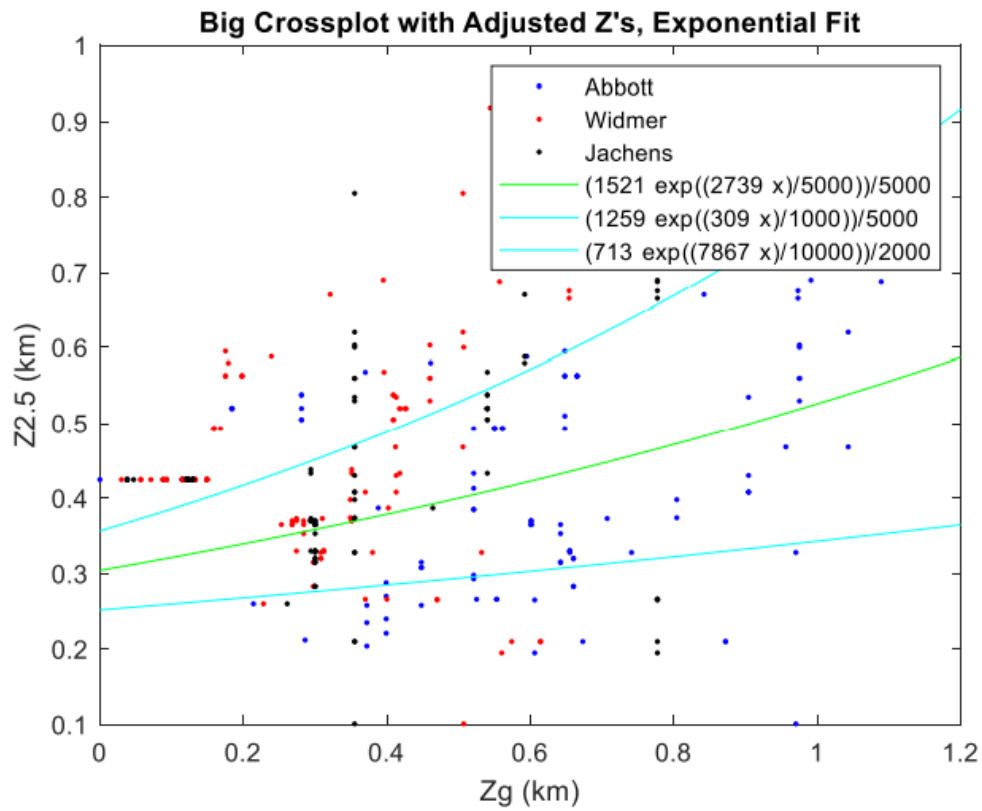


Figure 10: All Reno shear-wave data plotted against all Reno gravity data. Exponential model of Z2.5.

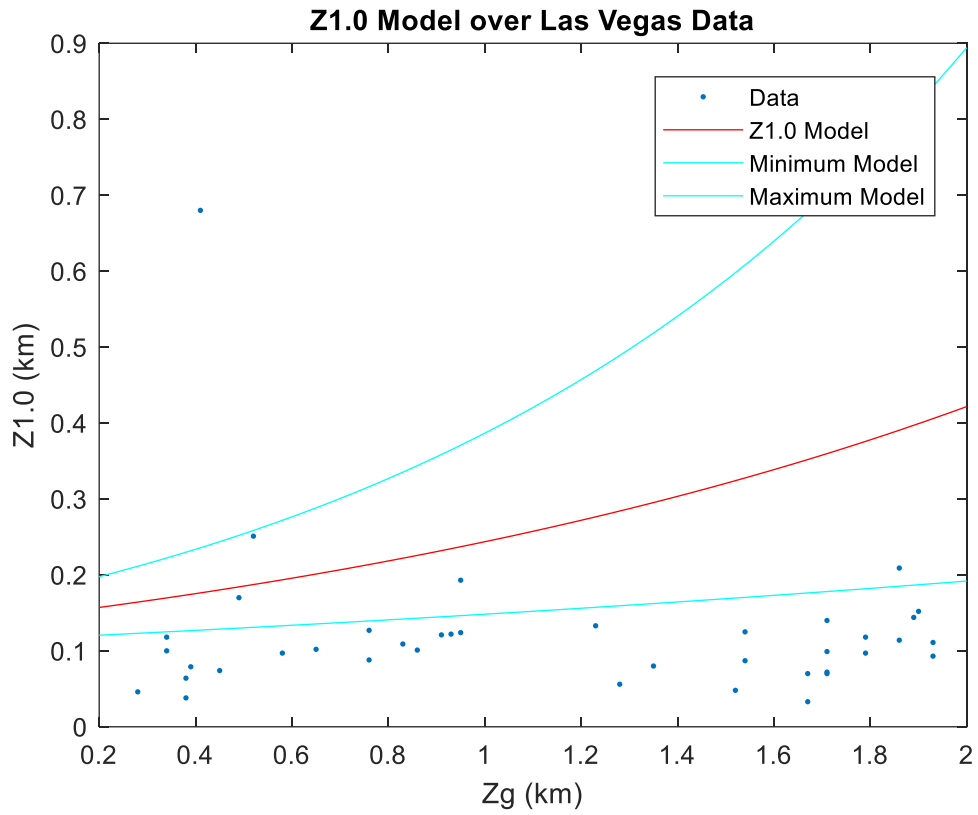


Figure 11: Z1.0 model applied to Las Vegas Shear-Wave Velocity Basin-Depth Data

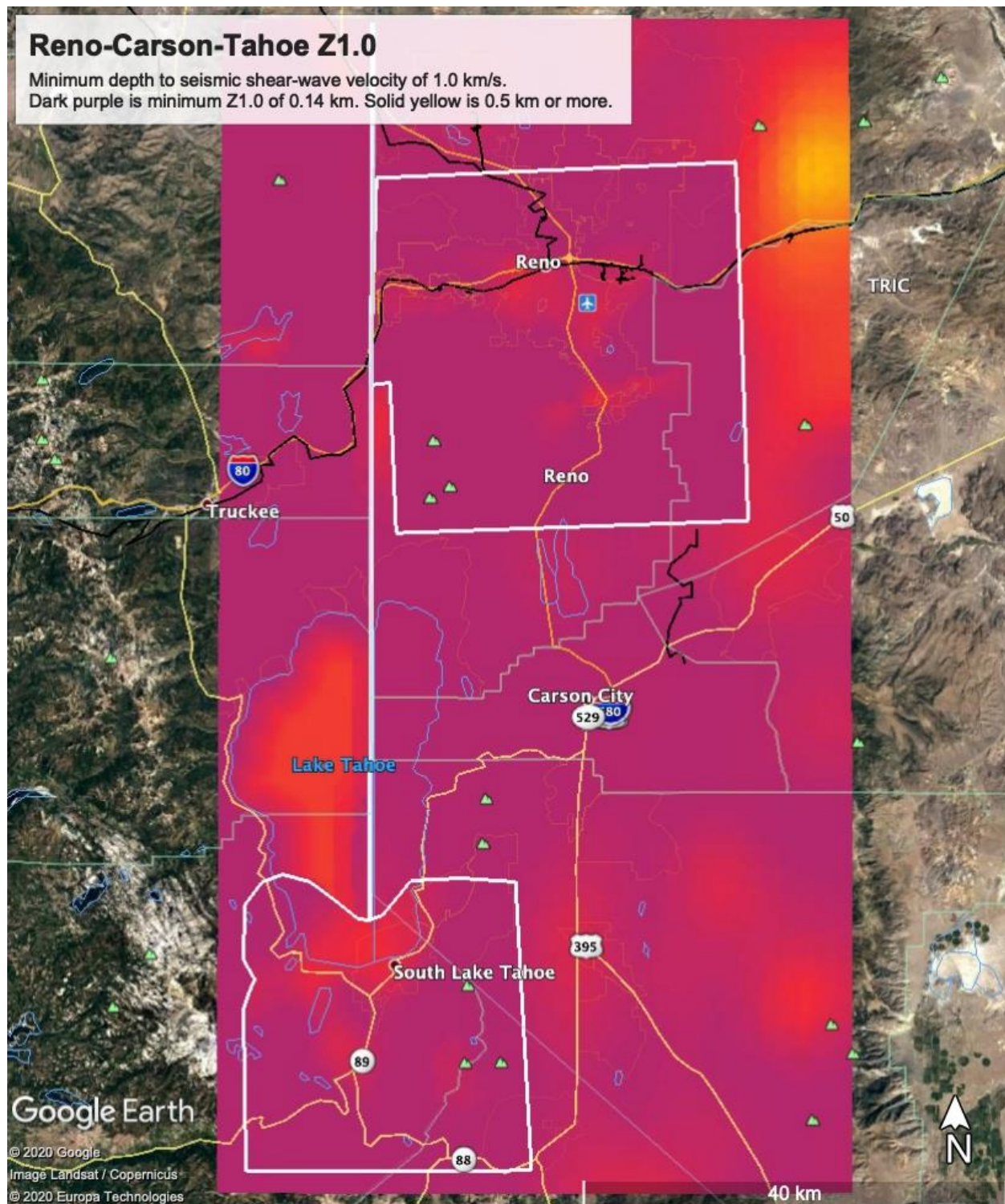


Figure 12: Z1.0 map for the Reno area. Z1.0 values estimated with Eq. 1 from Abbott and Louie (2000) Zg values are within the white-outlined area around Reno. Louie et al. (2016) provide Zg values as well as shear-velocity data in the South Lake Tahoe area, but we have not examined Z cross-plots for that region. Saltus and Jachens (1995) provide the remaining Zg values east of the vertical white line, which is the Nevada border at -120° longitude. West of -120°, basin thicknesses are guessed from bedrock proximity. The shape of the basin underlying the northwest part of Lake Tahoe is particularly uncertain.

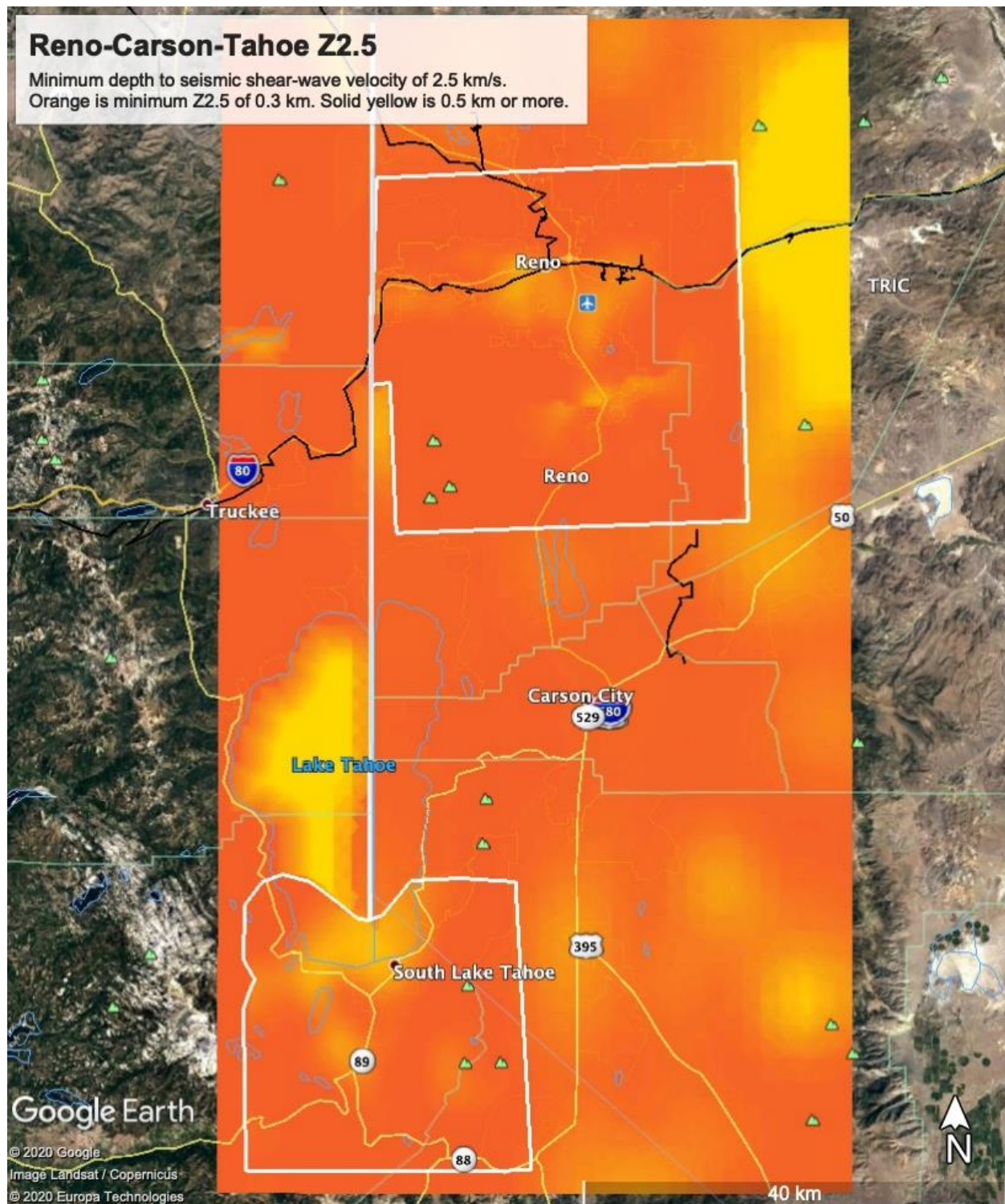


Figure 13: Z2.5 map for the Reno area. Z2.5 values estimated with Eq. 2 from Abbott and Louie (2000) Zg values are within the white-outlined area around Reno. Louie et al. (2016) provide Zg values as well as shear-velocity data in the South Lake Tahoe area, but we have not examined Z cross-plots for that region. Saltus and Jachens (1995) provide the remaining Zg values east of the vertical white line, which is the Nevada border at -120° longitude. West of -120°, basin thicknesses are guessed from bedrock proximity. The shape of the basin underlying the northwest part of Lake Tahoe is particularly uncertain.

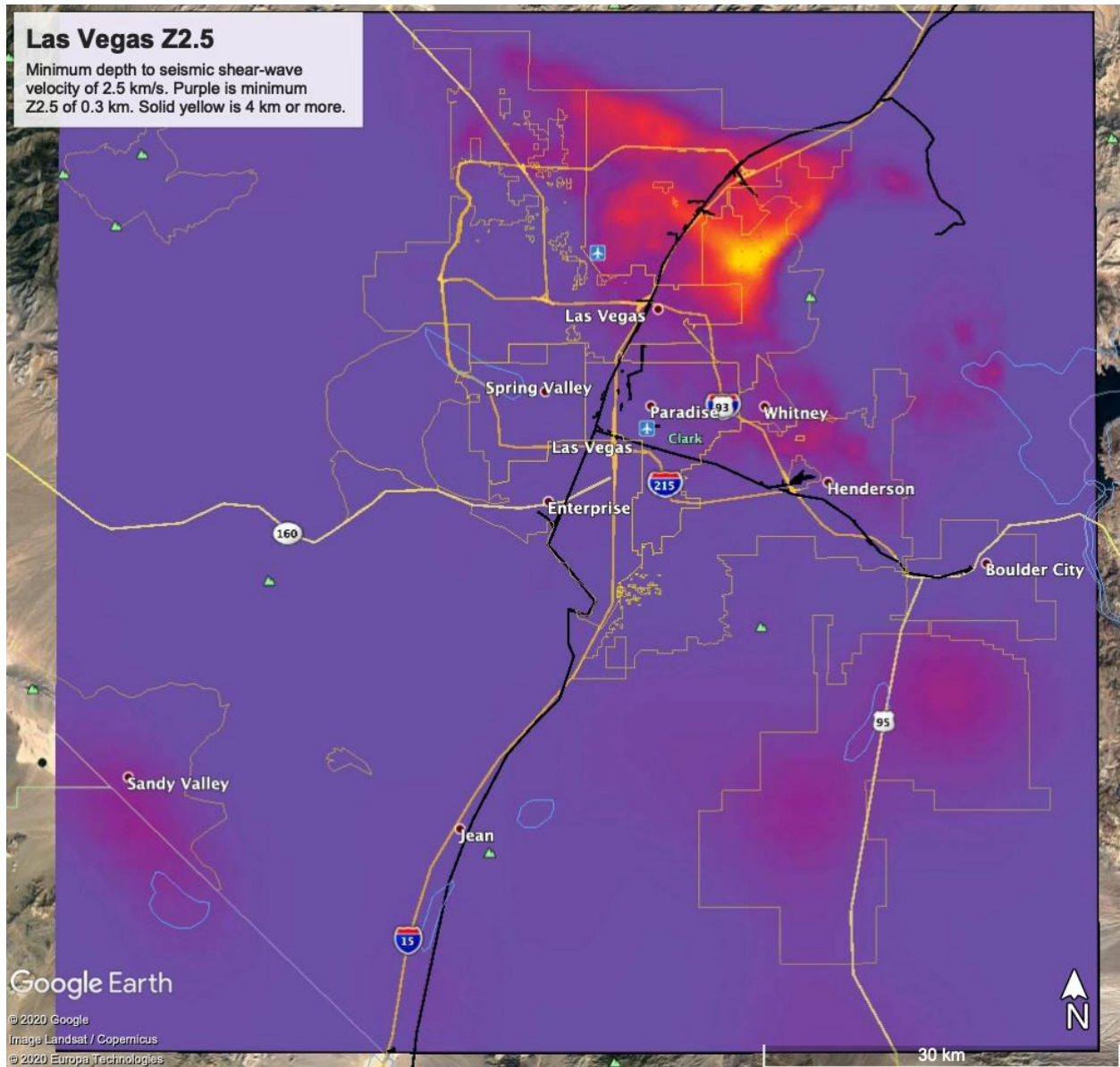


Figure 14: Z2.5 map for the Las Vegas area. Z2.5 values are estimated with Eq. 2 from Langenheim et al. (1998; 2001) Zg values in the northern half of the map. Saltus and Jachens (1995) provide the remaining Zg values.

Table 1: Selected Shear Velocity Measurements from Reno and Las Vegas
 Latitudes and Longitudes are in degrees and WGS84 datum. File names from Louie (2020a) archive.

File Name	Latitude	Longitude	Vs30 (m/s)	Z1.0 (km)	Z2.5 (km)	Zg (km)
1002-087.txt	39.5206	-119.808	461	0.064	>0.165	0.065
1002-354.txt	39.5275	-119.802	498	0.049	>0.059	0
1003-087.txt	39.5044	-119.808	461	0.064	>0.165	0.35
1004-087.txt	39.5045	-119.806	336	0.042	>0.200	0.35
1009-355.txt	39.5247	-119.806	511	0.027	>0.032	0.056
101-115-284.txt	39.51663	-119.705	616	0.113	>0.460	0
1010-355.txt	39.52463	-119.803	496	0.028	>0.032	0.012
1011-355.txt	39.5265	-119.803	498	0.037	>0.044	0.012
1016-355.txt	39.52732	-119.801	526	0.036	>0.115	0
116-130-284.txt	39.51478	-119.707	673	0.067	>0.340	0.018
131-145-284.txt	39.51321	-119.71	330	0.015	>0.340	0.018
161-175-288.txt	39.5127	-119.717	334	0.029	>0.275	0.092
236-250-288.txt	39.51137	-119.734	349	0.096	>0.440	0.375
356-364-289.txt	39.51523	-119.759	402	0.096	>0.220	0.376
416-430-353.txt	39.52204	-119.77	434	0.1	>0.270	0.141
646-660-312.txt	39.53055	-119.791	401	0.075	>0.330	0
661-675-312.txt	39.52984	-119.794	461	0.075	>0.230	0
691-705-313.txt	39.52942	-119.801	371	0.132	>0.215	0
766-775-313.txt	39.52438	-119.815	518	0.098	>0.265	0.155
776-790-319.txt	39.52433	-119.817	516	0.115	>0.340	0.265
791-805-319.txt	39.52259	-119.82	518	0.092	>0.320	0.28
836-850-319.txt	39.51998	-119.828	438	0.079	>0.300	0.406
851-865-319.txt	39.51982	-119.832	572	0.063	>0.310	0.474
881-895-340.txt	39.51918	-119.838	575	0.067	>0.330	0.541
896-910-340.txt	39.51764	-119.84	515	0.066	>0.325	0.619
911-925-340.txt	39.51635	-119.843	453	0.041	>0.320	0.722
926-940-340.txt	39.51499	-119.846	610	0.022	>0.425	0.702
941-955-340.txt	39.51231	-119.847	490	0.027	>0.330	0.812
956-970-353.txt	39.51101	-119.85	358	0.059	>0.350	0.812
BMHS.txt	39.4245	-119.765	400	0.077	>0.200	0.315
CCAD-PO-RS.txt	39.16403	-119.779	289	0.031	>0.131	0
CCAD-RS.txt	39.16403	-119.779	289	0.031	>0.131	0
CCAD-SDS-RS.txt	39.16403	-119.779	293	0.111	>0.152	0
CF02-RS.txt	39.1904	-119.742	277	0.045	>0.100	0
demo-UNRQuad.txt	39.53827	-119.814	398	0.044	>0.100	0.056
EagleValleyMiddleSchool-s2-remi.txt	39.15809	-119.722	310	0.096	>0.196	0
egge1-10.txt	39.53871	-119.815	588	0.065	>0.100	0.011
EGLV-RS.txt	39.15903	-119.719	303	0.039	>0.080	0
EVAN.txt	39.53915	-119.812	364	0.064	>0.164	0.011
fLine1_01_to_30_mod.txt	39.5276	-119.746	367	0.365	0.365	0.601

File Name	Latitude	Longitude	Vs30 (m/s)	Z1.0 (km)	Z2.5 (km)	Zg (km)
fLine1_03_to_32_mod.txt	39.5276	-119.745	361	0.365	0.365	0.601
fLine1_11_to_40_mod.txt	39.5276	-119.74	339	0.353	0.353	0.642
fLine1_13_to_42_mod.txt	39.5275	-119.739	350	0.315	0.315	0.642
fLine1_15_to_44_mod.txt	39.5275	-119.738	378	0.315	0.315	0.642
fLine1_17_to_46_mod.txt	39.5275	-119.737	395	0.283	0.283	0.66
fLine1_19_to_48_mod.txt	39.5274	-119.736	412	0.283	0.283	0.66
fLine1_21_to_50_mod.txt	39.5274	-119.735	418	0.32	0.32	0.66
fLine1_23_to_52_mod.txt	39.5273	-119.733	412	0.32	0.32	0.66
fLine1_25_to_54_mod.txt	39.5273	-119.732	418	0.328	0.328	0.655
fLine1_27_to_56_mod.txt	39.5274	-119.731	418	0.33	0.33	0.655
fLine1_29_to_58_mod.txt	39.5274	-119.73	418	0.33	0.33	0.655
fLine1_31_to_60_mod.txt	39.5274	-119.729	418	0.33	0.33	0.655
fLine2_01_to_30_mod.txt	39.5127	-119.82	384	0.275	0.568	0.37
fLine2_04_to_33_mod.txt	39.5127	-119.819	367	0.285	0.538	0.281
fLine2_22_to_51_mod.txt	39.5125	-119.808	525	0.438	0.438	0.13
fLine2_31_to_60_mod.txt	39.5129	-119.803	565	0.33	0.33	0.115
HVGC-RS.txt	39.49113	-11.7208	265	0.142	>0.150	0
Line1_01_to_30_mod.txt	39.5349	-119.715	317	0.273	0.563	0.665
Line1_02_to_31_mod.txt	39.5276	-119.746	367	0.365	0.365	0.601
Line1_03_to_32_mod.txt	39.5359	-119.715	317	0.273	0.563	0.665
Line1_04_to_33_mod.txt	39.5364	-119.715	304	0.26	0.563	0.665
Line1_05_to_34_mod.txt	39.5276	-119.744	361	0.37	0.37	0.601
Line1_06_to_35_mod.txt	39.5373	-119.715	304	0.26	0.563	0.648
Line1_07_to_36_mod.txt	39.5276	-119.743	361	0.37	0.37	0.601
Line1_08_to_37_mod.txt	39.5382	-119.715	316	0.245	0.563	0.648
Line1_09_to_38_mod.txt	39.5276	-119.742	339	0.365	0.365	0.642
Line1_10_to_24_mod.txt	39.504	-119.848	365	0.063	0.21	0.673
Line1_10_to_39_mod.txt	39.5391	-119.715	336	0.23	0.595	0.648
Line1_11_to_25_mod.txt	39.5047	-119.846	374	0.064	0.195	0.606
Line1_11_to_40_mod.txt	39.5395	-119.715	336	0.22	0.51	0.648
Line1_12_to_26_mod.txt	39.5049	-119.844	430	0.112	0.265	0.606
Line1_13_to_27_mod.txt	39.5049	-119.842	377	0.107	0.266	0.553
Line1_13_to_42_mod.txt	39.5404	-119.715	329	0.22	0.493	0.648
Line1_14_to_28_mod.txt	39.5051	-119.839	377	0.107	0.266	0.553
Line1_15_to_44_mod.txt	39.5413	-119.715	329	0.22	0.493	0.521
Line1_16_to_30_mod.txt	39.5049	-119.835	377	0.107	0.266	0.525
Line1_17_to_46_mod.txt	39.5424	-119.715	295	0.193	0.413	0.521
Line1_19_to_48_mod.txt	39.5432	-119.715	316	0.195	0.298	0.521
Line1_1_to_15_mod.txt	39.5008	-119.871	287	0.084	0.328	0.741
Line1_21_to_50_mod.txt	39.5441	-119.715	316	0.19	0.293	0.521
Line1_23_to_52_mod.txt	39.545	-119.715	316	0.183	0.288	0.399
Line1_25_to_54_mod.txt	39.5459	-119.715	316	0.17	0.27	0.399

File Name	Latitude	Longitude	Vs30 (m/s)	Z1.0 (km)	Z2.5 (km)	Zg (km)
Line1_27_to_56_mod.txt	39.5468	-119.715	316	0.168	0.24	0.399
Line1_29_to_58_mod.txt	39.5477	-119.715	309	0.169	0.221	0.399
Line1_2_to_16_mod.txt	39.5014	-119.867	272	0.098	0.468	0.956
Line1_31_to_60_mod.txt	39.5486	-119.715	309	0.158	0.212	0.286
Line1_3_to_17_mod.txt	39.5016	-119.865	259	0.084	0.468	1.043
Line1_4_to_18_mod.txt	39.5013	-119.861	299	0.115	0.6	0.975
Line1_5_to_19_mod.txt	39.5008	-119.859	235	0.084	0.101	0.97
Line1_6_to_20_mod.txt	39.5011	-119.857	287	0.077	0.328	0.97
Line1_7_to_21_mod.txt	39.5019	-119.855	348	0.046	0.21	0.872
Line1_8_to_22_mod.txt	39.5024	-119.853	348	0.046	0.21	0.872
Line2_01_to_30_mod.txt	39.5418	-119.722	269	0.27	0.493	0.561
Line2_02_to_31_mod.txt	39.5418	-119.721	269	0.25	0.493	0.561
Line2_03_to_32_mod.txt	39.5127	-119.819	367	0.285	0.538	0.281
Line2_04_to_33_mod.txt	39.5419	-119.72	273	0.248	0.493	0.561
Line2_05_to_34_mod.txt	39.5127	-119.818	423	0.398	0.505	0.281
Line2_06_to_35_mod.txt	39.5419	-119.719	268	0.248	0.493	0.55
Line2_07_to_36_mod.txt	39.5128	-119.817	423	0.413	0.505	0.281
Line2_08_to_37_mod.txt	39.5418	-119.718	268	0.248	0.493	0.55
Line2_09_to_38_mod.txt	39.5129	-119.816	469	0.393	0.52	0.281
Line2_10_to_24_mod.txt	39.4978	-119.863	403	0.24	0.535	0.904
Line2_10_to_39_mod.txt	39.5418	-119.716	268	0.248	0.493	0.55
Line2_11_to_25_mod.txt	39.4971	-119.863	382	0.25	0.43	0.904
Line2_11_to_40_mod.txt	39.5129	-119.815	480	0.393	0.52	0.184
Line2_12_to_26_mod.txt	39.4965	-119.864	382	0.263	0.408	0.904
Line2_12_to_41_mod.txt	39.5418	-119.715	268	0.216	0.493	0.55
Line2_13_to_27_mod.txt	39.496	-119.865	382	0.263	0.408	0.904
Line2_13_to_42_mod.txt	39.5129	-119.813	486	0.393	0.52	0.184
Line2_14_to_28_mod.txt	39.4952	-119.865	421	0.22	0.398	0.804
Line2_14_to_43_mod.txt	39.5418	-119.714	263	0.173	0.433	0.521
Line2_15_to_29_mod.txt	39.4943	-119.866	415	0.183	0.374	0.804
Line2_15_to_44_mod.txt	39.5125	-119.812	486	0.393	0.52	0.184
Line2_16_to_30_mod.txt	39.4934	-119.867	415	0.233	0.373	0.707
Line2_16_to_45_mod.txt	39.5418	-119.713	263	0.178	0.385	0.521
Line2_17_to_46_mod.txt	39.5124	-119.811	486	0.393	0.52	0.184
Line2_18_to_47_mod.txt	39.5418	-119.712	263	0.178	0.385	0.521
Line2_19_to_48_mod.txt	39.5124	-119.81	525	0.433	0.433	0.13
Line2_1_to_13_mod.txt	39.5056	-119.864	382	0.395	0.918	1.098
Line2_20_to_49_mod.txt	39.5418	-119.71	264	0.17	0.315	0.448
Line2_21_to_50_mod.txt	39.5125	-119.809	525	0.433	0.433	0.13
Line2_22_to_51_mod.txt	39.5418	-119.709	264	0.175	0.308	0.448
Line2_23_to_52_mod.txt	39.5125	-119.808	525	0.37	0.37	0.13
Line2_24_to_53_mod.txt	39.5418	-119.708	264	0.175	0.308	0.448

File Name	Latitude	Longitude	Vs30 (m/s)	Z1.0 (km)	Z2.5 (km)	Zg (km)
Line2_25_to_54_mod.txt	39.5127	-119.806	554	0.37	0.37	0.13
Line2_26_to_55_mod.txt	39.5417	-119.707	264	0.143	0.258	0.448
Line2_27_to_56_mod.txt	39.5128	-119.805	554	0.37	0.37	0.115
Line2_28_to_57_mod.txt	39.5418	-119.706	267	0.158	0.258	0.372
Line2_29_to_58_mod.txt	39.5128	-119.804	565	0.373	0.373	0.115
Line2_30_to_59_mod.txt	39.5418	-119.705	267	0.148	0.235	0.372
Line2_31_to_60_mod.txt	39.5418	-119.704	266	0.136	0.204	0.372
Line2_4_to_18_mod.txt	39.5024	-119.865	382	0.345	0.805	1.043
Line2_5_to_19_mod.txt	39.5015	-119.865	401	0.263	0.62	1.043
Line2_6_to_20_mod.txt	39.5005	-119.865	401	0.323	0.603	0.975
Line2_7_to_21_mod.txt	39.5005	-119.862	401	0.418	0.56	0.975
Line2_8_to_22_mod.txt	39.4996	-119.862	401	0.288	0.56	0.975
Line2_9_to_23_mod.txt	39.4988	-119.862	382	0.25	0.53	0.975
Line3_11_to_25_mod.txt	39.5121	-119.861	395	0.205	0.688	1.089
Line3_13_to_27_mod.txt	39.5112	-119.857	395	0.185	0.733	1.084
Line3_14_to_28_mod.txt	39.5108	-119.854	395	0.218	0.675	0.973
Line3_15_to_29_mod.txt	39.511	-119.852	403	0.168	0.665	0.973
Line3_16_to_30_mod.txt	39.5117	-119.85	403	0.186	0.713	0.812
Line3_1_to_15_mod.txt	39.5096	-119.884	395	0.22	0.58	0.461
Line3_3_to_17_mod.txt	39.51	-119.88	403	0.25	0.588	0.595
Line3_6_to_20_mod.txt	39.5109	-119.873	395	0.205	0.67	0.842
Line3_8_to_22_mod.txt	39.5113	-119.868	395	0.205	0.69	0.991
LOVE.txt	39.5199	-119.806	450	0.117	>0.151	0.065
NMHS-RS.txt	39.53166	-119.777	370	0.11	>0.120	0.013
NMHS.txt	39.53155	-119.776	434	0.074	>0.200	0.013
NOAA-RS.txt	39.56819	-119.796	401	0.101	0.138	0
NOAA.txt	39.5681	-119.796	407	0.04	>0.150	0
PICO.txt	39.43036	-119.775	350	0.077	>0.200	0.176
RF05.txt	39.50946	-119.837	581	0.125	>0.200	0.495
RF08.txt	39.54262	-119.856	521	0.151	>0.200	0.197
RFMA.txt	39.51951	-119.901	436	0.096	>0.200	0.167
RFNV.txt	39.57392	-119.829	597	0.07	>0.150	0
SF02.txt	39.55564	-119.733	296	0.084	>0.150	0.086
SKYF-RS.txt	39.48209	-119.836	275	0.108	>0.122	0.253
SKYF_RF07.txt	39.48272	-119.835	337	0.102	>0.150	0.253
SPHI.txt	39.5438	-119.76	355	0.124	>0.200	0.431
SWTP-RS.txt	39.51574	-119.704	552	0.007	0.163	0
SWTP.txt	39.51592	-119.704	731	0.119	>0.301	0
UNRN.txt	39.5272	-119.819	376	0.099	>0.200	0.265
vrrt5-12.txt	39.47587	-119.672	620	0.025	>0.050	0.034
VSTA1-s1-remi.txt	39.5746	-119.829	664	0.032	>0.132	0
VSTA2-s2-remi.txt	39.5746	-119.829	833	0.036	>0.136	0

File Name	Latitude	Longitude	Vs30 (m/s)	Z1.0 (km)	Z2.5 (km)	Zg (km)
VSTA3-s7-remi.txt	39.5746	-119.829	533	0.03	>0.200	0
VSTA4-s2-remi.txt	39.5746	-119.829	526	0.026	>0.200	0
WTP-s6-remi.txt	39.5159	-119.702	623	0.041	>0.141	0
WYRD.txt	39.49228	-119.76	294	0.063	>0.200	0.569
Below from Las Vegas:						
transect2000A.txt	36.11343	-115.185	431	0.68	>0.400	0.41
transect2000B.txt	36.11125	-115.185	420	0.079	>0.400	0.39
transect2001A.txt	36.18891	-115.142	306	0.14	>0.240	1.71
transect2002A.txt	36.179	-115.149	389	0.048	>0.148	1.52
transect2002B.txt	36.17693	-115.149	391	0.07	>0.200	1.67
transect2002C.txt	36.17486	-115.149	409	0.033	>0.177	1.67
transect2100A.txt	36.10542	-115.186	467	0.1	>0.300	0.34
transect2100B.txt	36.10368	-115.186	441	0.118	>0.300	0.34
transect2100C.txt	36.10194	-115.186	423	0.046	>0.146	0.28
transect2101A.txt	36.15009	-115.165	498	0.193	>0.293	0.95
transect2101B.txt	36.14812	-115.166	510	0.122	>0.222	0.93
transect2101C.txt	36.14614	-115.168	577	0.124	>0.300	0.95
transect2102A.txt	36.15739	-115.16	458	0.133	>0.400	1.23
transect2200A.txt	36.13524	-115.179	661	0.088	>0.400	0.76
transect2200B.txt	36.13301	-115.18	571	0.102	>0.202	0.65
transect2200C.txt	36.13078	-115.181	529	0.097	>0.400	0.58
transect2201A.txt	36.14124	-115.174	494	0.101	>0.201	0.86
transect2201B.txt	36.13929	-115.176	524	0.109	>0.400	0.83
transect2201C.txt	36.13733	-115.178	537	0.127	>0.227	0.76
transect2202A.txt	36.14322	-115.173	400	0.121	>0.300	0.91
transect2203B.txt	36.12594	-115.186	580	0.251	>0.400	0.52
transect2203C.txt	36.12345	-115.186	439	0.17	>0.270	0.49
transect2300B.txt	36.21264	-115.128	567	0.093	>0.300	1.93
transect2300C.txt	36.2106	-115.13	503	0.111	>0.211	1.93
transect2301A.txt	36.1959	-115.14	286	0.118	>0.400	1.79
transect2301B.txt	36.19372	-115.141	229	0.097	>0.197	1.79
transect2301C.txt	36.19154	-115.142	302	0.099	>0.199	1.71
transect2400A.txt	36.2084	-115.131	454	0.152	>0.252	1.9
transect2400B.txt	36.20633	-115.133	363	0.144	>0.244	1.89
transect2500A.txt	36.20217	-115.136	299	0.209	>0.400	1.86
transect2500B.txt	36.2002	-115.137	327	0.114	>0.400	1.86
transect2501A.txt	36.12146	-115.19	484	0.074	>0.174	0.45
transect2501B.txt	36.11921	-115.19	454	0.038	>0.200	0.38
transect2501C.txt	36.11696	-115.19	436	0.064	>0.234	0.38
transect2502A.txt	36.16715	-115.155	477	0.125	>0.225	1.54
transect2502B.txt	36.165	-115.156	481	0.08	>0.180	1.35
transect2502C.txt	36.16285	-115.157	502	0.056	>0.222	1.28

File Name	Latitude	Longitude	Vs30 (m/s)	Z1.0 (km)	Z2.5 (km)	Zg (km)
transect2503A.txt	36.17255	-115.15	436	0.07	>0.170	1.71
transect2503B.txt	36.17082	-115.152	424	0.072	>0.200	1.71
transect2503C.txt	36.16909	-115.154	481	0.087	>0.187	1.54