\subsection{Noise Data}

To determine the relationship between real estate price and road traffic noise levels, we first created a traffic noise exposure surface by calculating the propagation of traffic noise over the landscape using the FHWA (Federal Highway Authority) 1978 standard \citep{Barry1978}. Following \citet{Barry1978}, the traffic noise level at any given location on the landscape is given by:

\begin{eqnarray}\label{eq:noise}

L\_{EQ}(i) &=& \bar{L}\_0(i) + 0.115 \sigma \_i^2 + 10 log \frac{N\_i \pi D\_0}{T\*S\_i} + 10 log \left[ \frac{D\_0}{D}\right]^{1 + \alpha} \nonumber \\

&& + 10 log \left( \frac{\psi \_{\alpha (\phi \_1, \phi \_2)}}{\pi}\right) + \Delta \_{gradient} + \Delta \_{shielding}

\end{eqnarray}

where $L\_{EQ}(i)$ is A-weighted hourly energy equivalent noise level in decibels (dBA), which is calculated for each class $i$ of vehicle (automobile and trucks); $\bar{L}\_0(i)$ is the mean Sound Pressure Level (SPL) at the reference distance for class $i$; $\sigma \_i$ is the standard deviation of the SPL for each class of vehicle; $N\_i$ is the number of vehicles of the $i^{th}$ class passing during the relevant hour; $D\_0$ is the reference distance (usually 15 m); $D$ is the perpendicular distance from the road center line to the receiver; $\alpha$ is a site parameter (soft and hard surface), $0 < \alpha < 1$; $S\_i$ is the mean speed of the $i^{th}$ class; $T$ is the duration, usually 1 hour; $\phi \_1$ and $\phi \_2$ are the angles from the perpendicular of the limits of the observer's view of a section of the road. They are used to account for only the energy coming from a portion of the roadway; $\Delta \_{gradient}$ is an adjustment for road surface gradient; $\Delta \_{shielding}$ is a shielding adjustment (land cover, buildings, noise barriers).

To calculate the traffic noise map for the region using the above model, several data sources were used. A 2007 road centerline and the associated traffic characteristics (volume and proportion of trucks and vehicles) for the region were obtained from the Minnesota Department of Transportation (MNDoT). We converted the posted speed of each road into a GIS layer. For all roads without recorded traffic volume (i.e., residential), we assigned 100 vehicles/day as a minimum estimate. This estimate was based on factors identified in the literature as important for estimating traffic volume, such as census data on commuting population, tract area, the size of a standard street block, and road type \citep{Cheng1992, Fricker1986}.\footnote{In order to assess the sensitivity of our results to our estimate of traffic volume for local roads, we also ran the model using 200 and 300 vehicles/day for one county. With the exception of a few areas in the rural part of the county, there was less than 0.05 dBA difference at 30 m from the road centerline.}

Data on traffic volume and the proportion of trucks and vehicles on each segment of the road were averaged over a 24-hour period, making it impossible to account for a day and night time variation in traffic noise. Following \citet{Arditi2007}, we divided the total traffic volume into day and nighttime periods by assuming that 80 percent of vehicles and 65 percent of trucks are driven during the daytime (6am -- 10pm) and 35 percent of trucks and 20 percent of vehicles are driven during the nighttime (10pm--6am). Values for ground absorption were chosen by assuming that all road surfaces consisted of impervious bitumen. For computational simplicity, we created the road surface gradient by re-sampling US Geological Survey 30 m resolution Digital Elevation Model (DEM) to 100 m resolution.

We used three data sources for the shielding adjustment: buildings, foliage, and noise barriers. We extracted the perimeter and height of 818,500 buildings using aerial photography and LiDAR data. For the areas where LiDAR data are available, we used LiDAR Analyst$^{TM}$ software to extract buildings’ footprints. For the areas of the region where only aerial photos are available, we used Feature Analyst$^{TM}$ software to extract building footprints. For measurements extracted using aerial photography, height was determined using a combination of parcel data and field measurements.

The locations chosen for the traffic noise levels were the 818,500 buildings in the entire urban area. Thus, we used the perimeter and height of these buildings to account for the shielding effect of buildings. To account for foliage shielding (and to make the computation manageable), we assumed that only forest patches that are at least 10 m high and have an area greater than 10,000 m$^2$ will have a significant effect on noise attenuation. Accordingly, we extracted forest polygons with these characteristics using a combination of year 2005 land use data and 2001 National Land Cover Data (NLCD). To account for noise barrier shielding, we used a noise barrier layer obtained from MNDoT, which contains the locations, width, and height of noise barriers in the region.

We used the SoundPlan$^{TM}$ noise modeling software to implement the model given by Equation~\eqref{eq:noise}. Predicted traffic noise output is calculated at a grid resolution of 10 m$^2$.\footnote{We conducted a preliminary validation of the model output by comparing it with observed noise levels at 134 locations that were sampled along major highways. For each location, two readings were taken very close to the highway, one between 9am and 10am and another between 1pm and 2pm. The noise level for each location is then determined by averaging the two observed values, and this average is then compared with the predicted noise level. The relationship between the mean observed and predicted noise levels is linear and moderately strong with a correlation of 0.76. It is not surprising that the relationship is not stronger given the size and complexity of the model. In particular, the traffic volume data that we used for modeling traffic noise propagation is a 24-hour average, which requires more time-interval sampling per location than just the two used in the validation. Still, this preliminary comparison serves as a good indicator of how well this model captures traffic noise levels.} Once the noise surface for the entire region was developed, we extracted the noise surface for the present study area by overlaying the housing parcel boundaries and calculating the maximum noise level within the parcel.