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PROBLEM

Transportation planning and project development is moving toward a model of including environmental information and potential impacts earlier in regional, corridor, and project planning. Thus, the type and quality of this information and how well it meets the needs of transportation planners is critical. Road/highway effects from the existence and use of infrastructure are pervasive throughout developed landscapes, but seldom measured, modeled, visualized, and/or used in planning and transportation decision-making. This means that the evaluation of potential transportation alternatives, potential impacts, and potential mitigation activities are not based on the actual distribution of effects from the transportation infrastructure.

This project was designed to investigate and geographically model the numerous effects roads have on the surrounding environment. We isolated several of these effects and looked at them in greater detail, developing a model that represents the various interactions between a road and the surrounding region. The model was designed to be a proof-of-concept of a stand-alone tool for environmental and transportation planners in local and state agencies.

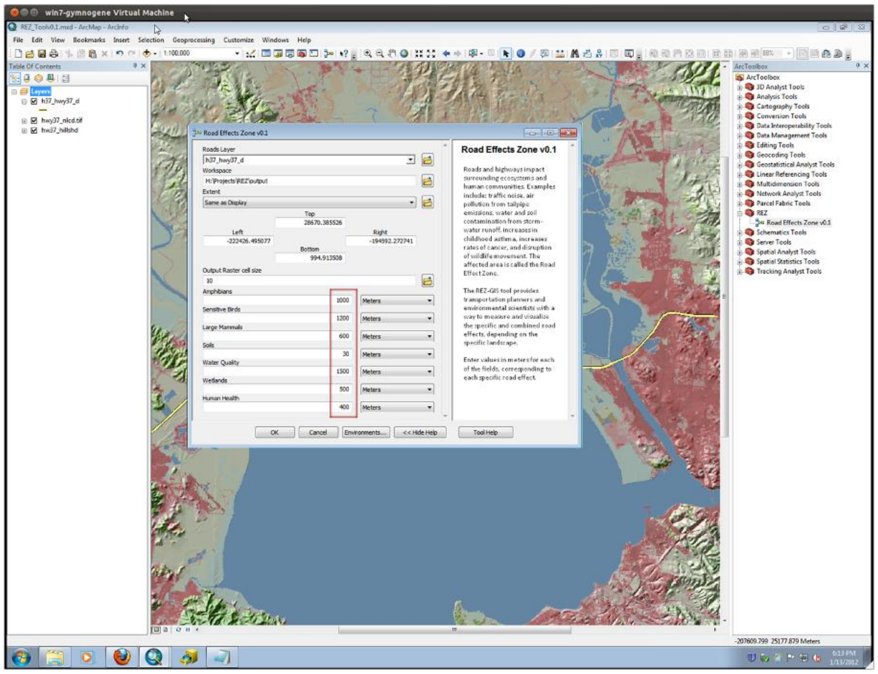
Capturing the extent and intensity of transportation system impacts allows for the development and improvement of sustainable transportation systems. Planning that begins with a spatial expression of the types and intensities of current potential future system impacts is more likely to result in infrastructure with less impact and the perception that the transportation agency is acting as a steward of natural and human values. Transportation bills (ISTEA, SAFETEA-LU) have been migrating toward increased recognition of environmental values and early inclusion of environmental values and potential impacts in decision-making. This tool provides spatially-explicit expression of these potential impacts and can inform both early planning and project-scale measurement of mitigable impacts.

KEY FINDINGS

There were two key findings from the study: 1) a simple GIS tool based on road effect distances in the literature could be developed, with simple features and explanatory text, and 2) specific road effects (i.e., traffic noise) could be modeled in the context of measuring overall road effects.

The pilot tool (REZ v0.1) is an easy-to-run extension in ArcGIS, with a graphic user interface that includes default values for road effects drawn from the literature, as well as the option for the user to enter their own values (Figure 1). The REZ v0.1 tool returns both individual road effects (e.g., effects on birds) and combined effects – a summation of effects, which dissipate with distance from roads.

The traffic noise model was developed to be part of an ultimate REZ tool that has more accurate effect zone mapping. This model (SPreaD 2.0) projects sound intensity from roads, based on traffic volumes & composition, topography, land-cover, and climatic conditions. It can be run as a stand-alone and the data added to the REZ v0.1 outputs, or eventually integrated within a comprehensive REZ tool.



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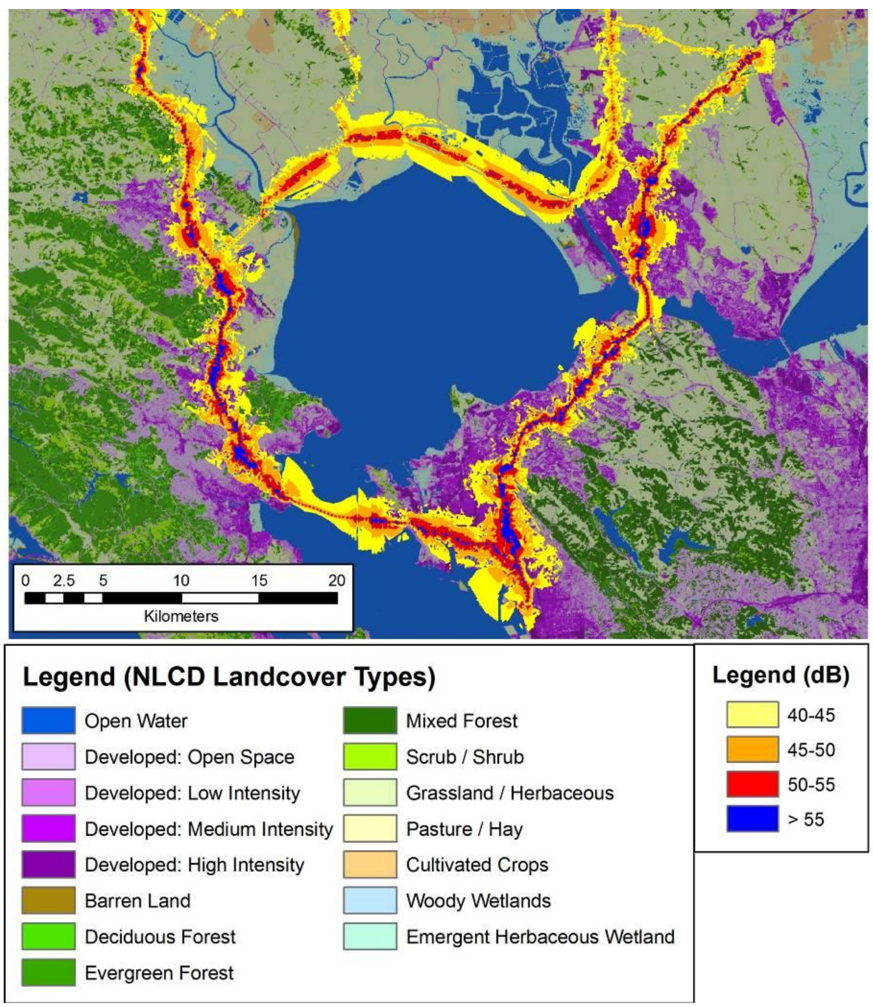

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Figure 1 A. Road Effect Zone GIS tool (REZ-GIS) user interface in ArcGIS environment. B. Traffic Noise propagation from highways in the North San Francisco Bay.

METHODOLOGY

Two main types of activities were carried out: 1) a simple GIS tool was developed that spatially expressed road effects based upon values from the literature and 2) a specific road effect, traffic noise, was modeled as an example of a road effect for which purpose-built models are available.

GIS Tool Development

The Road Effects Zone GIS Tool v0.1 was developed in ESRI's ArcMap v10. It was built using a combination of ArcMap's Model Builder interface and customized code in Python, a programming language. Model Builder provides a flexible framework to create a user interface, chain together other GIS library functions, and produce an output raster which represents the road effects on various environmental attributes. The data input and processing model is built around the idea that roads are buffered to different distances, depending on the specific road effect (Figure 2). Python code was used to validate, test, and optimize the model. The tool's user interface accepts the necessary user-provided input parameters, such as the roads map-layer, the processing extent for the output raster data, a grid cell size for the output raster, and a series of distance values (from the road) which represents various road effects. The user data entry includes intelligent filters so that only numeric data is accepted in the distance variables, and that only line data is accepted for a roads layer. Default values were assigned to most distances based on various scientific studies, but obviously, a user can change these distances for a specific region or species. The units of measure for the distances variables are managed and provided by ArcMap so standardizing on a measurement wasn't necessary. The REZ tool buffers the roads layer according to the user input variables, creates raster representations of the buffered area, and then combines these data to produce the final REZ output data layer.

The REZ GIS Tool can be added to the ArcGIS Toolbox and integrated with the ArcGIS working environment. This ability enables the tool to be combined with other ArcGIS functions, and one could build additional, region-specific tools whose output, for example the traffic noise model, could be the direct input to the REZ GIS Tool.

Road Effect	**Effect Distance (m)**	**Citation**
Amphibians	1000	Eigenbrod et al., 2009
Sensitive birds	1200	Forman et al., 2002
Large mammals	600	Gagnon et a., 2007
Soil contamination	30	Backstrom et al., 2003
Wetlands processes	500	Findlayand Houlahan, 1996
Human health	400	Raaschou-Nielsen, 2011; Spira-Cohen et al., 2011

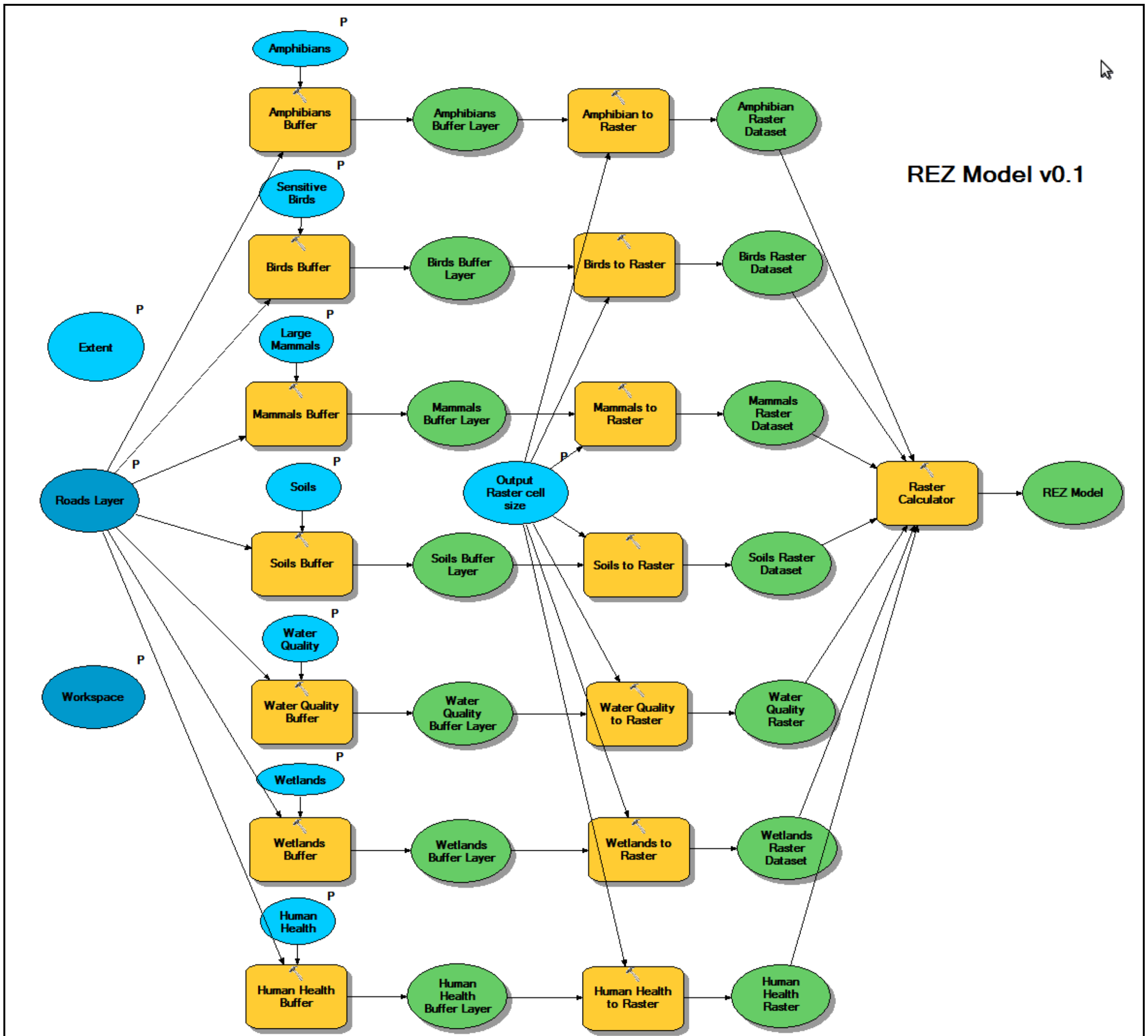

Figure 2 Data input and processing model for the REZ-GIS model.

Specific Effects Modeling – Traffic Noise

As a proof of concept for modeling specific effects of transportation, we focused on one of the more challenging components, accurately calculating the traffic noise envelopes around roads. We used the noise model, System for the Prediction of Acoustic Detectability (SPreAD) version 2.0, developed at the Center for Landscape Analysis (UC Berkeley) by Sarah Reed, now at Colorado State University, to estimate the sound envelope around part of state highway 99 in the Central Valley and regional highways in the North San Francisco Bay Area (Figure 3). We compared the model results to wildlife occurrences in the Department of Fish and Game's California Natural Diversity DataBase (CNDDB) to evaluate how noise effects could impact threatened animals.

SPreAD is an ArcGIS toolbox plug-in for modeling sound propagation from a single point source across the landscape. A series of points along a road are used to estimate noise production from the road or highway. SPreAD was originally a spreadsheet routine developed by the U.S. Forest Service and the Environmental Protection Agency to study recreational noise in US National Parks and Forests. Reed updated the model, converting the lookup tables to formulas, and introducing other spatial data as available for the model.

SPreAD generates a raster GIS layers whose values represent sound propagation (in decibels dBA) across space from a single sound source (for example, an automobile). Single sound sources may be definedThe model requires several additional data layers including:

Land Use Model – The National Landcover Dataset (NLCD) is a spatial data representation of various land uses across the landscape, including classes to represent open water, urban areas, grasslands and herbaceous shrubs, forests, wetlands and riparian regions. This dataset was downloaded from the USGS Landcover Institute[1] (LCI).

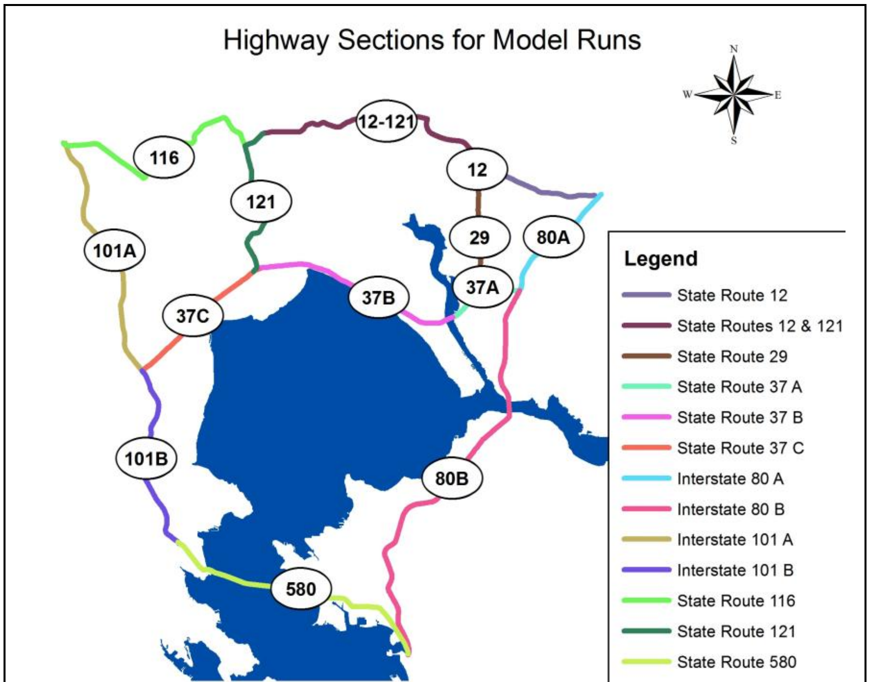

Figure 3 Sample study area and highways, North San Francisco Bay.

Digital Elevation Model – This data layer provides the terrain features. Geomorphological features can be barriers and prevent sound from propagating outward; the sound model does not account for sound moving around such objects. The DEM data were downloaded from the USGS Seamless Server[2] at a 10 meter resolution. The resolution needed to run SPreAD is 100 feet (approximately 30.5 meters), so this layer needed to be re-sampled to change the scale and make it align with the NLCD layer. There was a special technique to follow in ArcGIS to ensure that the two grids align with each other, where the formula needed to build the raster (from the Raster Calculator found in the Spatial Analysis Tools):

[new_dem] = resample([rez_dem.tif, 30.0008771, cubic)

This resample uses a cubic convolution matrix to determine the size of the larger grid cell.

Sound Frequency and Ambient Sound – As audible sound wave spectrum ranges from approximately 50 Hz to 1200 Hz, the sound model allows the user to choose the frequency with which to run the model and estimate sound propagation. Certain species of animals and specific calls/behaviors are affected at different frequency ranges, so this tool models sound propagation at different frequencies.

With the frequency chosen for the model run, an ambient sound layer is generated based on certain sound values entered for that region. These values can be measured from sampling that region, or values found in the scientific literature.

The ambient sound estimate is an important layer in the model because it is subtracted from the total sound propagation layer from the sound source's baseline noise propagation to generate an excess noise calculation, isolating the contribution made from the single point or linear sound source.

Modeling Sound from a Single Point – To model sound production from a single point, the sound source is defined as a single point in a GIS data layer (shapefile). The following information is collected to properly run this sound propagation routine:

- Single point representing the source source – In ESRI Shapefile format.
- The extent of the model, which is a defined area for which to run the model, which would be a subset of the greater landscape for the study region.
- Sound frequency (Hz) – important sound frequencies (e.g., to sensitive birds)
- Sound source level (dB) – loudness of the point source

1 http://landcover.usgs.gov/

2 http://seamless.usgs.gov/

- Measuring distance (ft) – the model works by determining the sound level from the source to each of grid cells in the model's extent. This distance value is used to calibrate the sound value.
- Elevation dataset – the Digital Elevation Model assembled.
- Land Cover dataset – the NLCD data assembled.
- Air Temperature (F) – an average or other temperature for the study region, based on the seasonal conditions selected below.
- Relative humidity (%)
- Prevailing wind cardinal direction (deg)
- Wind speed (mph)
- Seasonal conditions – a combination of the following for environmental factors, including clear or cloudy, windy or calm, summer or winter, and day or night.
- Ambient source conditions layer

The length of time to run a single point analysis is dependent on the size of the extent being modeled. Our model runs took about five minutes to run one point. The model generates numerous intermediate layers and we are working with Dr. Reed to make the model more efficient and faster for ad hoc analyses.

RESULTS

This project was designed to investigate the numerous effects roads have on the surrounding environment. We isolated several of these effects and developed a model GIS tool that represents the various interactions between a road and the surrounding region. These road effects could be expressed in a GIS environment, based on user-inputs. A traffic noise model was used to estimate the extent and intensity of this road effect. We also summarized environmental attributes within the traffic noise effect zone as an example of evaluation of road effects useful during early transportation planning.

REZ-GIS Tool

The tool functioned as an ArcGIS extension, using data provided and delivering an approximate road effect zone in raster format, based on user inputs (Figures 4). An important caveat is that the mapped extent of road effects are based on un-conditional buffering of the highway. In other words, variation in topography and land cover are not used to change the extent and decay rate of effects from the road.

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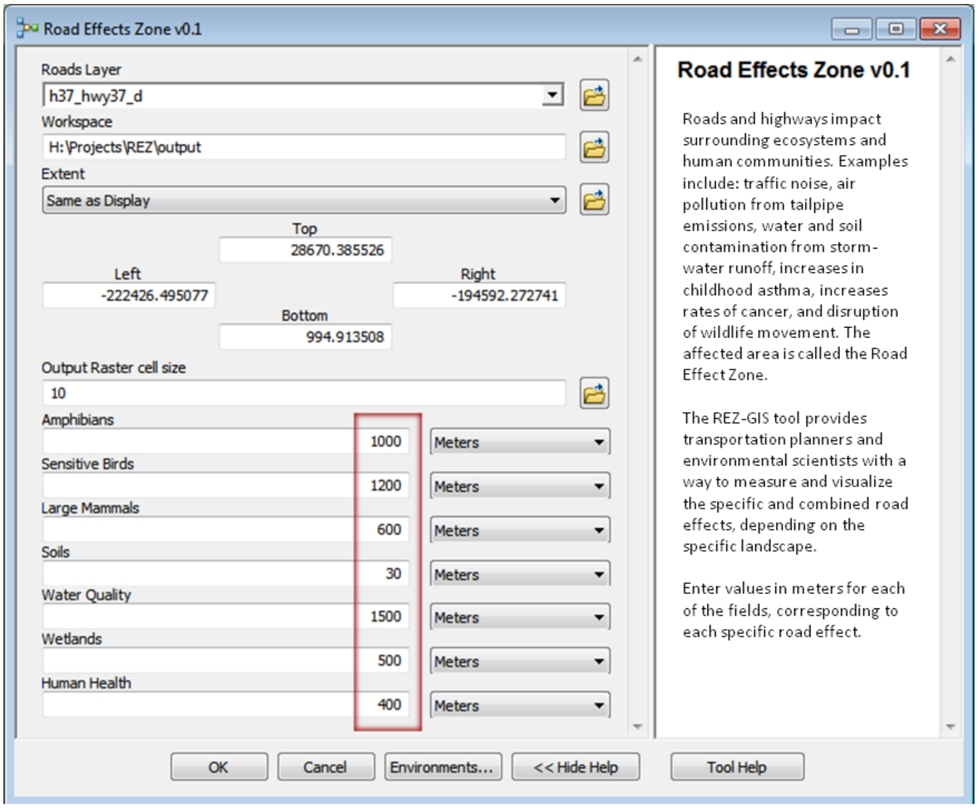

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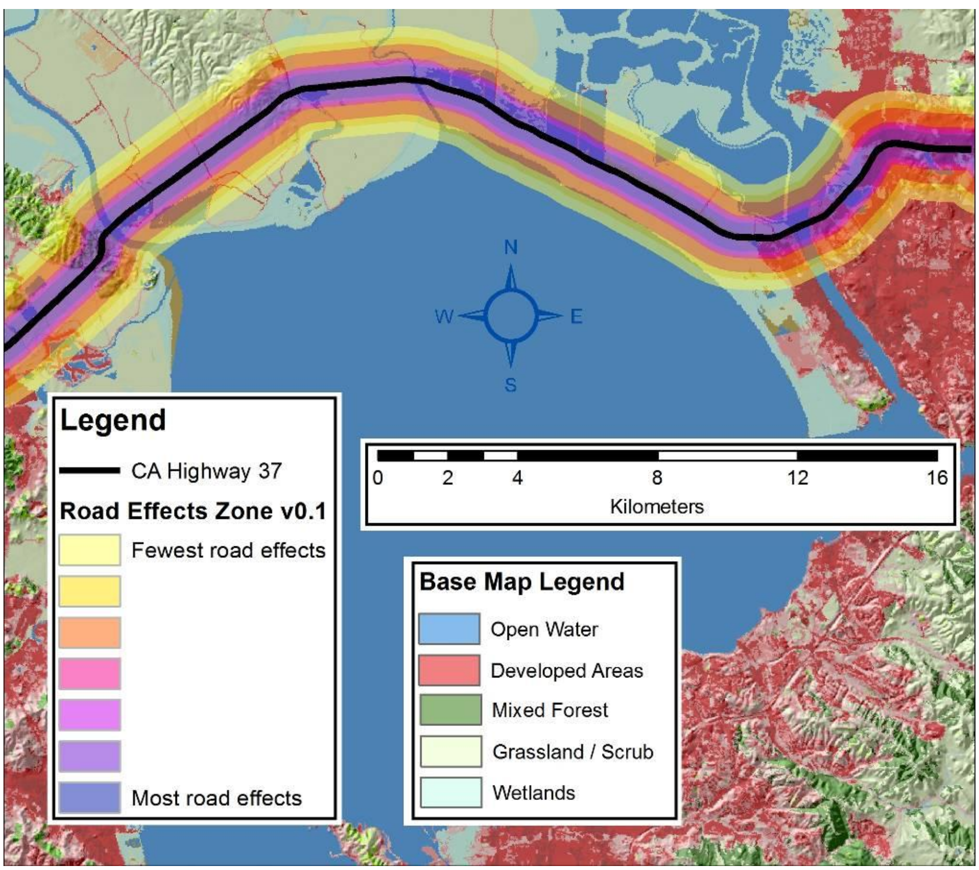

Figure 4 A. User interface for REZ-GIS tool. Fields indicated with the red box contain default road effect distance values from the literature which can be modified by the user.

Specific Road Effect: Traffic Noise

Traffic noise effects extended for several hundred meters to almost 3 km for several highways in a variety of California landscapes (Figure 5). The variability of distance and the sheer extent of this effect are new types of information for any contemporary transportation planning process.

A noise level cutoff of 40 dB was used to indicate the sound intensity around state highway 99 that can disturb certain sensitive bird species (Figure 5A). Animal, plant and habitat occurrences in the California Natural Diversity Database (CNDDB) intersecting with this sound-affected area may be disturbed by traffic noise (Figure 5B). This type of intersection provides transportation planners and environmental regulatory agencies with a way of estimating the impacts of current and proposed transportation projects on species and habitats of management concern.

Traffic noise can affect both natural and human system well-being. Estimating traffic noise impacts on highways in a region with varying traffic intensities provides a mechanism for both calculating total transportation impacts, as well as understanding trade-offs inherent in developing different transportation corridors. In the North San Francisco Bay region, traffic noise impacts vary considerably among highways with different traffic volumes and in different natural settings and communities (Figure 5B). These varying impacts are critical to understand if regional highway-specific and cumulative impacts are to be understood and used in transportation planning.

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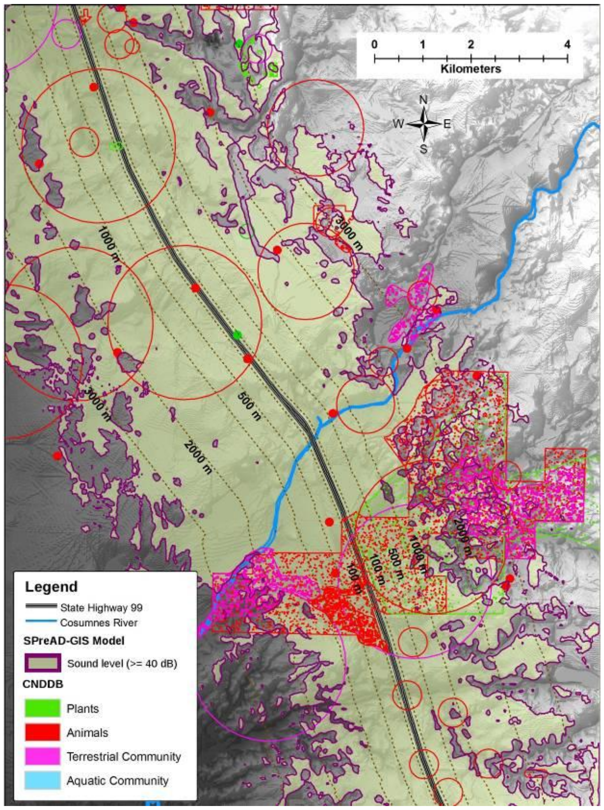

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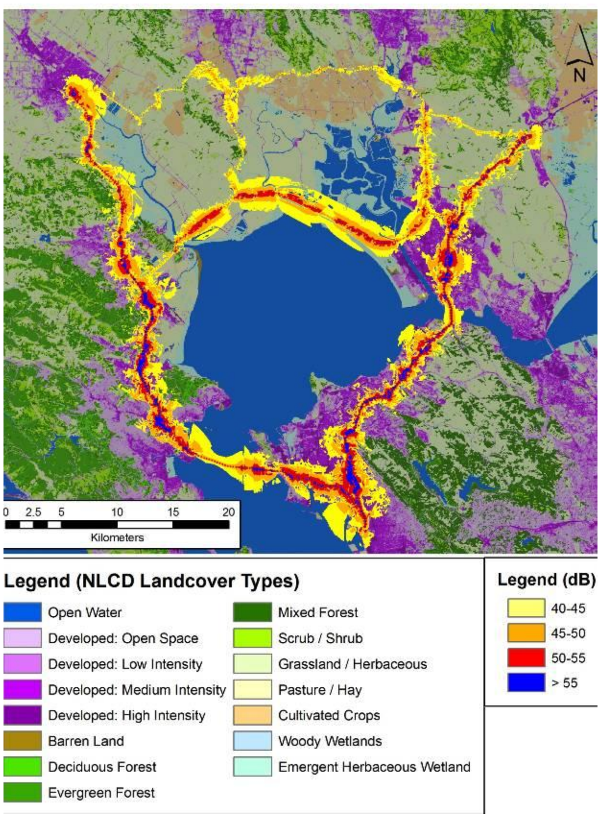

Figure 5 A. Traffic noise extent around state highway 99. The edge of the green area is 40dB, which is the noise intensity disturbing to certain birds. Plants, animals, and community types in the California Natural Diversity Database (CNDDB) that intersect with this noise extent are shown. B. Traffic noise extent for North San Francisco Bay region highways, overlaying land cover type (from the National Land Cover Database, NLCD).

CONCLUSIONS

This seed grant was intended to result in a proof-of-concept road effect zone model in GIS. We accomplished this, as well as modeling a specific road effect (traffic noise) using a sound propagation model. These two approaches of specific road effect modeling and a cumulative road effects tool can be combined to create a spatially detailed calculation of individual and cumulative road effects. This detailed model would be a large step forward in transportation planning and effects analysis where there are no such models in regular use. Creation of the tool in a familiar GIS environment is likely to result in a greater rate of adoption than a model with a less familiar look and feel.

RECOMMENDATIONS

1) Fully develop the road effect zone tool in GIS, complete with an operators Manual, to facilitate its use in transportation planning and environmental analysis.

2) Use the road effect zone model to estimate cumulative road effects for a region in California to demonstrate multi-scale (road segment to region) utility.

3) Model specific road effects (traffic noise and emissions) for California highways and/or a region to contribute to a refined road effects model and GIS tool.

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