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Improving Light and Soundscapes for Wildlife Use of Highway Crossing Structures

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Improving Light and Soundscapes for Wildlife Use of Highway Crossing Structures

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16. Abstract

Transportation and other agencies and organizations are increasingly planning and building under- and over-crossing structures for wildlife to traverse busy highways. However, if wildlife do not use these structures due to noise, light, and other factors, then the structures may have a low benefit to cost ratio. Several criteria are key for their success—sufficient safety and/or conservation need, cost, location, and anticipated use by wildlife. There is limited information in wildlife-crossing guidance on how wildlife biologists should advise designers, engineers, and architects on the use of structural and vegetation elements that could reduce noise and light disturbances. To address this problem, this study used field measurements and modeling of light and noise from traffic to inform and test the designs of two wildlife over-crossings. Wildlife-responsive designs were developed and tested for two crossings being considered or planned by California Department of Transportation in California. For the planned crossing of US 101 near the city of Agoura Hills (the Wallis-Annenberg crossing), the three designs consisted of noise/glare barriers; noise/glare barriers + berm; and noise/glare barriers + multiple berms. For the potential crossing of Interstate 15 south of Temecula, one design used noise/glare barriers of 3 different heights and the other had no barriers. Key limitations and opportunities for each design approach were identified. Creating "dark and quiet paths" using a combination of berms and noise/glare barriers could decrease disturbance in the crossing structure approach zones and increase the wildlife-responsiveness of the designs.

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Disclaimer

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List of Abbreviations

DTM	digital terrain model
FHWA	Federal Highway Administration
LCOC	Liberty Canyon wildlife overcrossing
PeMS	Performance Measurement System
TNM	Traffic Noise Model
TOC	Temecula overcrossing
WCS	wildlife crossing structure

Executive Summary

Traffic noise and light can change animal presence and behavior (Davies et al. 2013; Francis and Barber 2013; Goodwin and Shriver 2010; Li et al. 2009; Longcore and Rich 2004; Meillere et al. 2015; Shannon et al. 2014; Siemers and Schaub 2011). They can potentially deter wildlife from approaching roadways, except in areas where noise and light are less disturbing due to traffic volumes, topography, vegetation, and roadway structures. Lighting intensities and types, including fixed-position and vehicle-based, are increasingly being recognized as an important source of disturbance for wildlife in the vicinity of transportation (Caltrans 2019). Wildlife crossing structures are being built more frequently as mitigation for road and traffic impacts on wildlife. Although transportation agency biologists are aware of the potential for traffic noise and light to impede crossing structure use by wildlife, few tools are available to inform their advice to designers, engineers, architects, and habitat designers of the structural and vegetation elements that could reduce disturbance. Each structure represents a significant investment in time, money, and effort. If wildlife freely approach and enter these structures, the expected benefits from these costs are increased, including safer wildlife movement across the right-of-way and increased driver safety. If wildlife are hesitant to or refuse to approach structures due to noise, light, and other factors, then the structures have a much lower benefit to cost ratio.

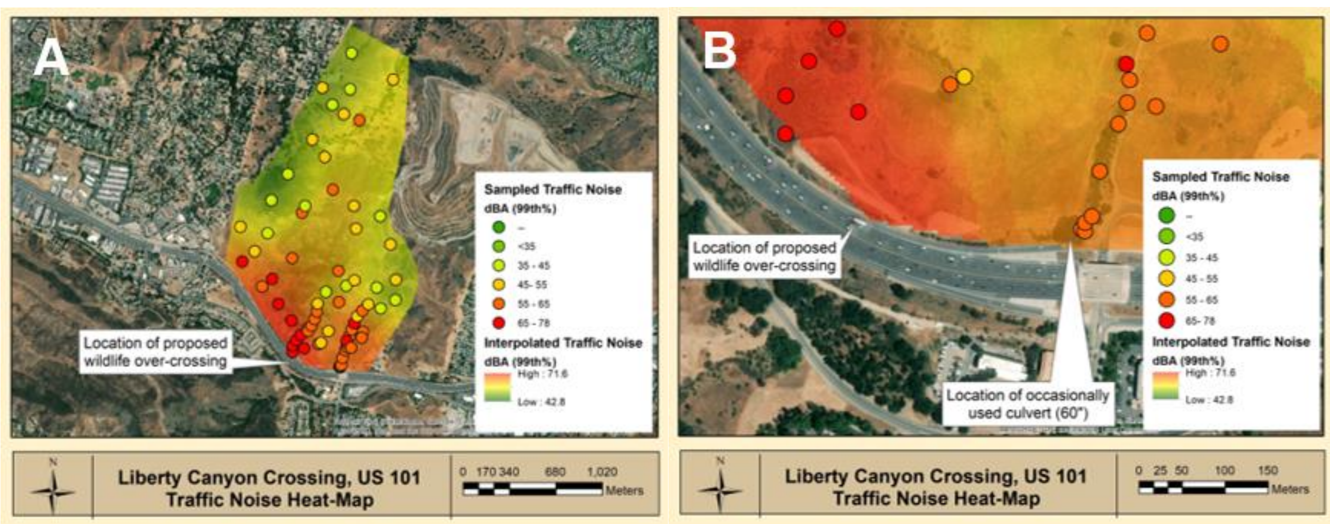

Figure ES1. A) Interpolated traffic noise and sampling locations on north side of approach to proposed Liberty Canyon over-crossing; and B) Close-up of approach zone to proposed crossing and location of culvert occasionally used by wildlife.

Consistent with the scientific literature, our findings and conclusions from previous work is that increasing traffic volume and resulting traffic noise and light can reduce sensitive species use of wildlife crossings. We have developed predictions of noise and light conditions that might impair wildlife use (Figure ES1). Identifying artificial noise and light conditions necessary for wildlife approach to crossing structures would be useful for Caltrans and partner agencies engaged in environmental mitigation planning. In addition, modeling the effect of landscape design on artificial noise and light conditions in the “approach zone” to crossing structures would help with designing future mitigations that are more broadly effective in passing wildlife. In the case of existing bridges in natural areas, modifications to the approach, or the bridges themselves to reduce noise and light could cost-effectively increase wildlife use.

We received interest in this approach from Caltrans staff in Districts 7 and 8 and worked with them during this project. The D7 staff were interested in a detailed modeling of the north and south approach zones to the proposed Liberty Canyon over-crossing (LCOC) to reduce traffic noise and light. The D8 staff were primarily interested in noise and light conditions that could affect wildlife approach to I-15 at one existing bridge over Temecula Creek, the Temecula over-crossing (TOC), and several other potential locations of built over/under-crossings. The LCOC is proposed to be the largest wildlife over-crossing in the world and to connect isolated mountain lion and other predator populations. The TOC is similarly proposed to connect isolated mountain lion populations, as well as being near a stretch of the interstate where there is a high density of mountain lion deaths from traffic. Both structures are in locations with very high traffic volumes and concomitant noise and glare propagation into nearby habitat.

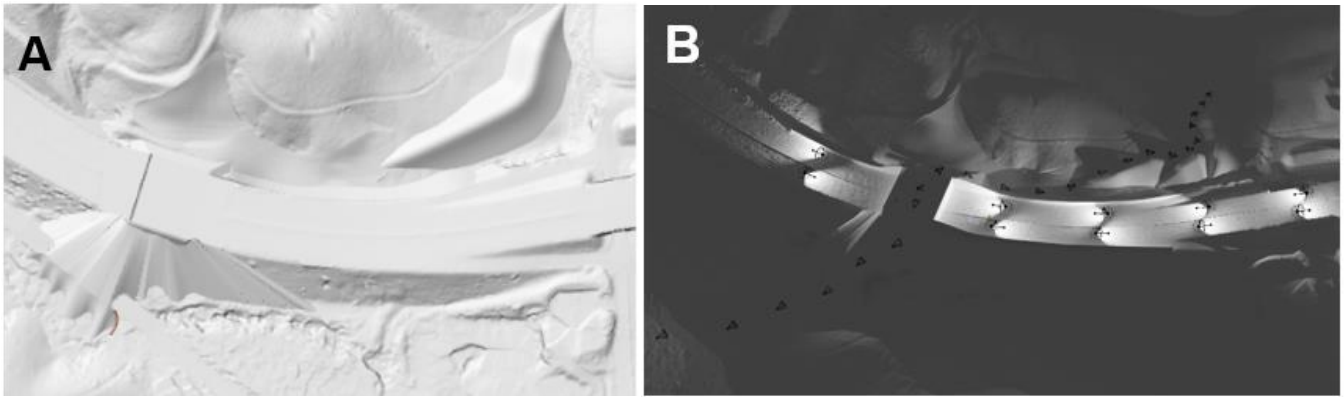

Figure ES2. A) Design of the approach zone of the crossing structure to inhibit traffic noise and light (single berm model); and B) Modeled propagation of traffic glare by designed infrastructure (barriers and 3-berm model).

Using available land elevation data, we artificially manipulated the approach zone to the LCOC using the design programs Rhino and Blender. We added noise/glare walls (hereafter “barriers”) and berms in positions that would theoretically reduce traffic noise and/or glare propagation from US 101 into the areas where wildlife would be expected to approach the crossing structure (Figure ES2). The side of the barriers away from the highway was back-filled with dirt to increase the sound-absorptive capacity of the barriers. Using the noise-propagation software Traffic Noise Model (TNM 3.0, FHWA 2019) and the light propagation tool in Blender, we tested different configurations of barriers and berms for how well they mitigated traffic noise and light coming from the highway. We quantified the relative benefits of these alternatives for suppression of noise and light in the approach zone of the crossing structures. We found that a single large berm using on-site materials, combined with barriers adjacent to the right-of-way provided the best overall suppression of noise and light for the LCOC. We carried out a similar design experiment for the potential Temecula over-crossing and similarly found barrier configurations that reduced noise and glare propagation into the wildlife approach zone.

Contents

Introduction

Wildlife crossing structures (WCSs) are often designed to optimize wildlife use. But this design is fairly ad hoc and generally coarse-grained, lacking details chosen for the scale of the individual animal or species. Despite the widespread recognition that artificial light and noise can affect wildlife in various ways, available guidance for wildlife crossing structures does not consider the existence of or mitigation treatments for traffic noise and light as wildlife approach the WCS and the roadway it traverses (e.g., Clevenger and Hujser, 2011). In fact, some guidance suggests that wildlife over-crossings are best positioned "in areas bordered by elevated terrain, enabling the approach ramps and surface of structure to be at the same level as the adjacent land" (Clevenger et al., 2017), a position that increases the likelihood that traffic noise and light will permeate the approach zone to the WCS. While preparing this report, the authors could only find one peer-reviewed article describing mitigation of traffic noise and glare as an essential feature of WCS design (Beben, 2016).

Wildlife are sensitive to a similar range of sound levels as humans are. These levels, or degrees of loudness, are usually measured as dB(A), or dB(C), weighting schemes based on human and animal hearing, or Leq, the equivalent continuous sound level. Vehicle noise can affect wildlife communication (Parris and Schneider 2008; Owens 2013), habitat occupancy (Davies et al. 2013; Goodwin and Shriver 2010), vigilance (Shannon et al. 2014; Li et al. 2009), predation efficiency (Siemers and Schaub 2011), predator avoidance behavior (Meillere et al. 2015), and various other behaviors (Longcore and Rich 2004; review: Francis and Barber 2013; Ware et al., 2015). Anthropogenic noise from various sources, including transportation, are pervasive throughout the US, including in protected areas that theoretically provide sanctuaries for wildlife (Buxton et al., 2018).

Anthropogenic noise and light propagate through landscapes differently and areas may be bright and quiet, or darker and noisy, depending on roads and nearby development (Buxton et al., 2020). Both traffic noise and illumination theoretically change at rates inversely proportional to the square of the distance from the road edge, but may be separately reflected and absorbed by structures, vegetation, geological formations, and atmospheric conditions (e.g., humidity). Dense vegetation and walls can dramatically reduce light levels but may allow some sound to pass through. Light colored vegetation may reflect light but absorb sound. This means that as animals approach wildlife crossing structures, they will encounter increasing and variable light and noise conditions. This heterogeneity and its effect on wildlife movement at fine scales is not well-characterized.

Given the sensitivity and responsiveness of many wildlife species to anthropogenic noise and light, an increase in traffic volume and resulting traffic noise and light would likely reduce the use of wildlife crossings by sensitive species. Identifying the anthropogenic noise and light conditions that would and would not interfere with the approach of wildlife to WCSs would be useful for transportation and conservation organizations engaged in environmental mitigation planning. We have previously quantified the traffic disturbance (noise and glare) conditions that can affect wildlife presence and behavior at wildlife crossing structures (Shilling et al., 2018 & 2020). We used field-measurements and modeled light/sound-scapes to describe possible opportunities and barriers to reduced-disturbance approach zones to existing and proposed crossing structures. We then designed combinations of wildlife over-crossings and noise/glare mitigation structures to identify possible design approaches to reduce traffic disturbance of wildlife attempting to use crossings. Modeling the effect of landscape design on artificial noise and light conditions in the “approach zone” to WCSs would help with designing future mitigations that are more broadly effective. In the case of existing WCS in natural areas, modifications to the approach, or the bridges themselves to reduce noise and glare could cost-effectively increase wildlife use.

Including Stakeholders

We worked with Caltrans District 7 and 8 staff to identify proposed crossing locations, or existing crossing structures, where more information about sound and light-scapes would be useful. Specifically, we worked with District 7 staff, landscape architect Clark Stevens, and the National Wildlife Federation to identify traffic noise and light disturbance in the approach zones to the planned Liberty Canyon wildlife over-crossing. We participated in a meeting of the Liberty Canyon Partners on 4/23/2020, during which we shared design goals and preliminary ideas, as well as findings from previous research. The main executive partners for the project include Caltrans, Mountains Recreation & Conservation Authority (MRCA), and the National Wildlife Federation (NWF). We also gave webinars on our design work on May 7, 2020 (for National Wildlife Federation) and on June 10, 2020 (for National Center for Sustainable Transportation). We shared information with these partners and shared our design approach with the design contractor Living Habitats developing the landscaping plan for the crossing. Finally, we gave a webinar on April 13, 2021, to Caltrans staff and others on our designs and preliminary noise and light abatement findings. We also coordinated and worked with District 8 staff and The Nature Conservancy on possible noise and glare impacts in areas near I-15, south of Temecula to assist with planning a potential wildlife over-crossing. The report findings were shared with the stakeholders prior to release of the report.

Approach

Field Investigations of Fine Scale Sound and Light-scapes

Study Sites

Two sites in California were chosen for their varying level of evaluation and planning for wildlife crossing structures (Figure 1): A) The proposed Liberty Canyon wildlife over-crossing (LCOC), in the city of Agoura Hills, and B) a possible site for a wildlife over-crossing south of the city of Temecula (TOC). Site A is in an active planning and evaluation process, the site for the crossing has been chosen, and construction is anticipated within 5 years. Site B is in an early, yet active, planning process with possible sites being considered and currently has no construction timeframe.

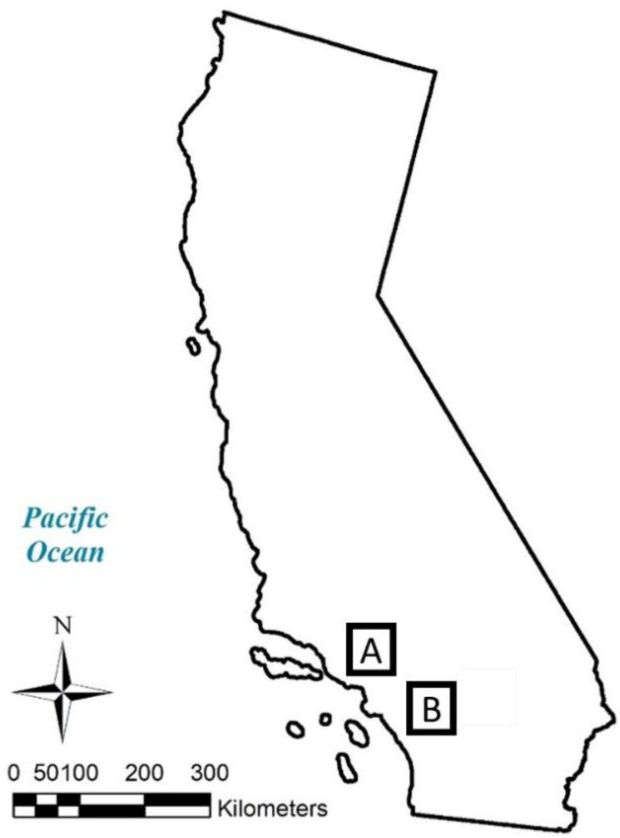

Figure 1. Locations of field measurements, modeling, and design for wildlife crossings. A) The proposed Liberty Canyon wildlife over-crossing (LCOC), US 101. B) The site of a possible wildlife over-crossing across I-15, south of Temecula (TOC).

We have previously carried out studies of traffic noise and light conditions near 26 structures throughout California, for example the proposed LCOC in Agoura Hills (site A, Figure 1). In this specific case, we took sound measurements at 70 locations and estimated traffic noise using interpolation in ArcGIS (Kriging). We carried out similar measurements on the eastern approach to site B across I-15.

Noise Measurements

We measured traffic noise across grids perpendicular to the approximate location of each proposed or potential wildlife crossing structure. Sound pressure levels were recorded in the daytime in A-weighted decibels (dBA) and C-weighted decibels (dBC) using digital sound level meter devices (TENMA 72-947 and PCE-322; 30-130 dBA/C range, set to fast). These are Class 2 sound meters (IEC 61672-1:2002), and were calibrated before each use with a Sound Level Meter Acoustical Calibrator with 94 dB output level (1 kHz). Recordings of at least 10 minutes were taken at each point, with the meters approximately 1-2 feet above the ground.

Light Measurements

Artificial light conditions (primarily from traffic glare in rural areas) can vary spatially in different ways from noise. We measured light during the new moon and after moon-set along transects perpendicular to the highway proposed for future crossings. The luminance of the upward hemisphere and total scalar illuminance were measured along these transects approximately 1 m, 10 m, 30 m, 50 m, 100 m, 200m, and/or 300 m from the road edges. Luminance is the brightness of the sky or landscape at any point as visible from that point of observation. Scalar illuminance is the amount of light, in lux, converging on the point of observation from all directions. We used a novel approach employing a camera with a very wide-angle lens to capture low light levels. The camera and images are, respectively, calibrated and processed with specialized software (Sky Quality Camera, Euromix Ltd., Llubjana, Slovenia; Jechow et al., 2017). We also measured color temperature of incident light, which is an important factor in disturbance of wildlife behavior and increasingly of concern to Caltrans (Caltrans, 2019).

Disturbance-Scapes

We interpolated sampled traffic noise and light to represent typical noise and light propagation conditions. For both noise and light, we used Kriging in ArcGIS, a commonly-used and robust method for interpolating sound conditions in geographic space (Tsai et al., 2009; Zuo et al., 2016), based on measured sound levels in that space. We also used a spatially-explicit, noise-propagation model (Traffic Noise Model, TNM, v3; FHWA 2019) to estimate noise levels on model landscapes, based on measured starting noise levels and land-cover (described below).

Wildlife-Responsive Design

Our study region for the LCOC was set by extent of the 1.5 foot resolution, digital terrain model (DTM) of a crossing, developed previously by one of us (Clark Stevens). We modified the crossing DTM using a bridge elevation DTM file from a Caltrans contractor to increase bridge thickness and height above the roadway (Robert Rock, personal communication). For the Temecula overcrossing (TOC) site we used the overcrossing location (Site 2) suggested by students in the College of Engineering at California Polytechnic University Pomona (CalPoly, 2018). We created two bounding extents for the TOC study region. The first was a 1-kilometer square centered on the potential overcrossing site. The second was a 4-kilometer square centered further north, selected to include the Santa Margarita River and the hills surrounding the overcrossing. We accessed 10-meter elevation data from the US Geological Survey (https://www.usgs.gov/core-science-systems/ngp/tnm-delivery/gis-data-download).

For each site, we imported elevation data into Rhino to create an initial land-form, then added virtual elements representing: 1) potential crossing structures, 2) sound barriers adjacent to the roadway, and 3) noise-absorbing berms in the LCOC approach zone to each of the crossing structures. For the LCOC site we created five test cases investigating the impact of terrain modifications, berms, and walls. For the TOC site, we created three test cases investigating the impact of the presence or absence of barriers. When modifying terrain, we outlined regions for editing based on visual site analysis. We used the 3D shape of the edit region outline, our estimates of water paths, and previously identified animal paths to create new surfaces in the edit region. For the LCOC, each design increased in complexity. In the approach zone to the LCOC, we virtually re-deployed a large amount of fill material that was excess from a previous construction project to create the virtual sound/light berms (and adjacent concavities/valleys) between the highway and the adjacent landscape. We used a modification of “ha-ha” walls as the preferred type of sound barriers because of their greater sound absorption compared to traditional sound walls. The modification was the inclusion of a half-berm on the side away from the roadway, meaning the vertical face of the wall faced the roadway and a sloped, earthen bank faced the adjoining landscape.

Evaluating Noise and Glare Reduction

We used the Federal Highway Administration’s (FHWA) Traffic Noise Model (TNM v 3.0) to simulate the traffic noise level at specific points in our study area (Figure 2) and create noise maps (referred to as Noise Contours in TNM). TNM was designed to be used to model noise propagation around noise abatement structures proposed near roadways. TNM uses (a) estimated traffic noise level at the roadway, (b) digital terrain models, and (c) land cover to estimate sound levels at different positions relative to the roadway. Terrain lines for TNM were made either by hand (LCOC) or automatically by creating contour lines corresponding to every 40 feet in elevation and at critical features (e.g., slope changes), terrain lines were made by creating points every 100 feet. Traffic conditions were obtained from the Performance Measurement System (PeMS, Caltrans).

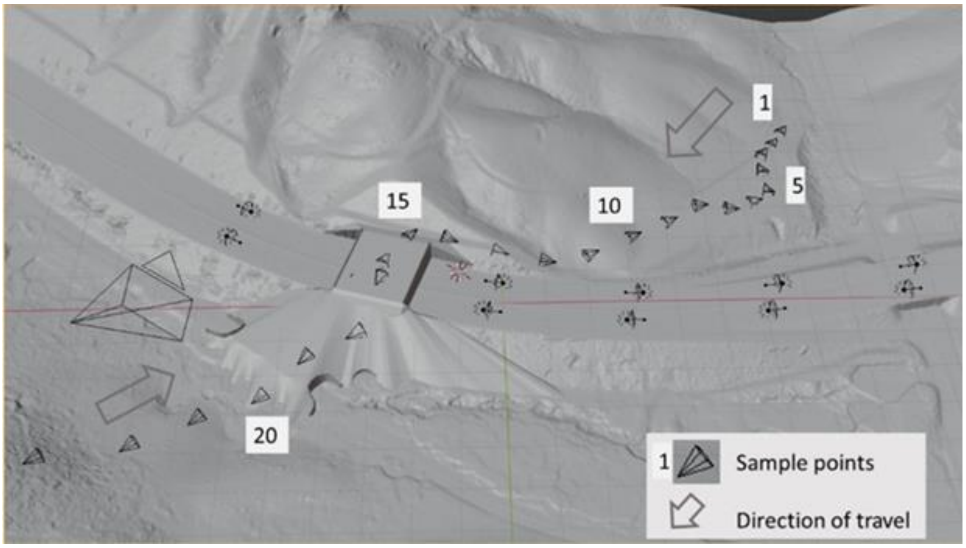

Figure 2. Locations of traffic glare and noise sample points in the approach zones and the bridge of the LCOC. (Numbers assigned to every fifth sample point are shown.)

For glare propagation, we estimated relative brightness using Blender to create viewpoint images and GIMP to estimate the lit and shadowed areas from passing vehicles at different sample points in the approach zone. We took images from the 3D illumination model in Blender from the perspective of an animal's view as it moved toward the crossing structure from the north or the south. We estimated brightness in GIMP 2.10.24 and expressed brightness as a percentage of the original, un-modified condition. Roadway lighting, sky-glow, and other light sources were not considered.

Results

Available Fill for LCOC Design

One limitation in the LCOC is the availability of fill to build the southern approach ramp to the crossing and other structural features. The total fill available on-site from the remnant fill pile and after terrain modification is ~2.31 million cubic feet (Table 1). This is only slightly more than the fill requirement for the southern approach ramp to the crossing (2.24 million cubic feet, Table 1). The different designs vary in their fill deficits: A) Design 2, with ramps, bridge deck, and noise barriers has a deficit of 326,000 cubic feet. At a cost of ~$4/cubic yard fill (A Runk, Contech Engineered Solutions, personal communication), filling this deficit would cost approximately $144,889 delivered from local sources; B) Design 3, with one berm, has a deficit of 2.03 million cubic feet, which would cost approximately $902,222 delivered from local sources; and C) Design 4, with three berms, has a deficit of 1.64 million cubic feet, which would cost approximately $728,889 delivered from local sources.

Table 1. Total fill available from terrain modification in the northern approach zone to the LCOC and fill needed for different components of the designs used. Fill volumes were calculated in ArcGIS using the cut/fill function for the design elements.

Fill Available/Needed	Volume (Cubic Feet)
Total fill available on-site	2,305,555
Fill needed, noise barriers	302,204
Fill needed, north approach ramp	32,313
Fill needed, south approach ramp	2,242,245
Fill needed, bridge deck	54,935
Fill needed, one berm	1,696,774
Fill needed, three berms	1,313,614

Disturbance-Scapes

1. LCOC

We used measured traffic noise levels to generate noise heat maps for the approach zone north of the proposed location for the LCOC (Figure 3A). The north side is higher in elevation than the highway and in many places faces toward or slopes toward the highway. In contrast, the southern approach zone is considerably lower (>20 m) than the highway, protecting it from traffic disturbance. The heat map helped to orient the noise/light mitigation structures in the northern approach zone. For example, the measured and interpolated noise levels were >65 dBA immediately adjacent to the proposed crossing site (boxed area, Figure 3A). In previous investigations, we found that traffic noise levels >55 dBA significantly reduced the likelihood of detecting bobcats north of the LCOC site (Figure 3B). To the east, noise levels were ~10 dBA lower, suggesting that connecting this area of lower noise to the crossing structure could be beneficial to moving wildlife. This lower noise area is also where wildlife moving in the vicinity of the proposed crossing site have been observed (S Riley, NPS, personal communication).

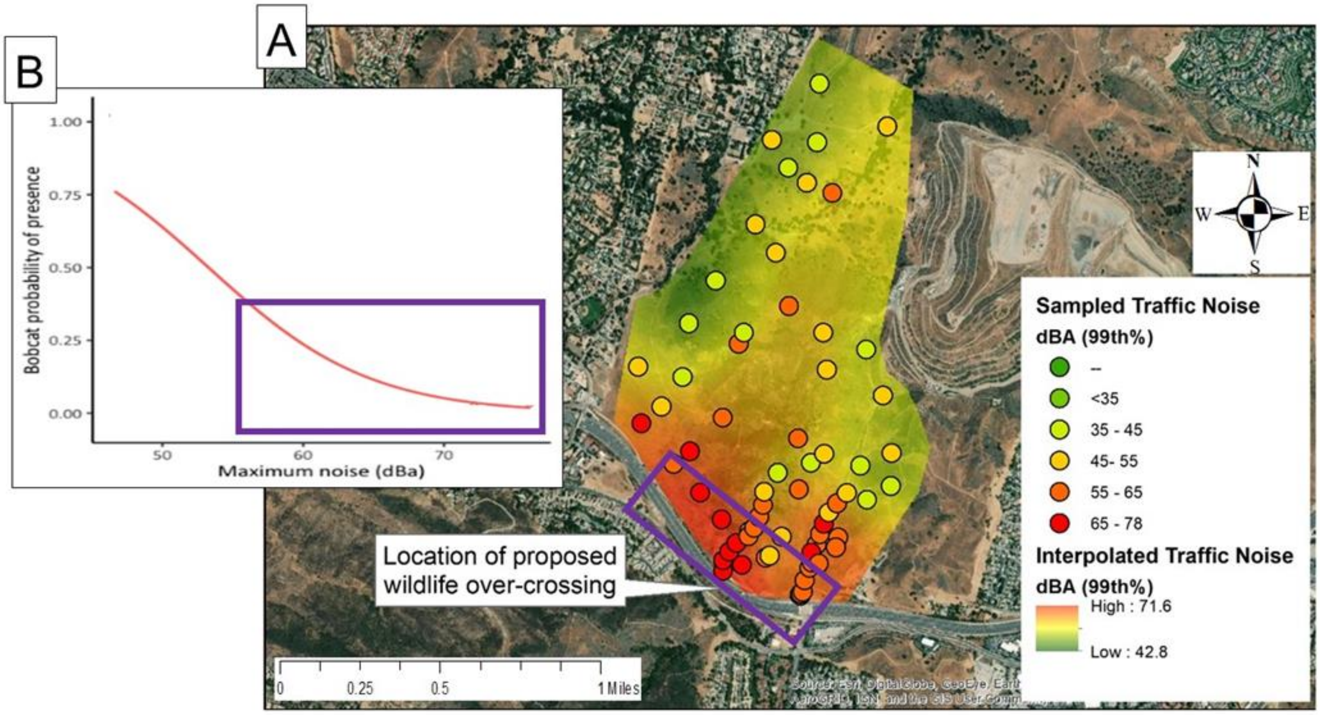

Figure 3. A) Field measured and interpolated traffic noise in the north approach to the LCOC; (B) Probability of bobcat occurrence in relation to maximum traffic noise (99th%, dBA), previously determined in LCOC northern approach zone. Purple box highlights areas of noise >55 dBA (A) and equivalent bobcat occurrence probability with noise >55 dBA (B).

We also used field-measurement of light to approximate where glare in approach zones to the proposed crossing location could inhibit wildlife movement (Figure 4). Scalar illumination represents the light conditions on measured points on the landscape, which includes traffic illumination. The ridgelines that run north from the proposed crossing location were generally brighter than the area immediately south of the proposed crossing site and in the creek bed that is to the east of the crossing site and north of the highway (Figure 4A). We measured light conditions for each point facing north or south. Luminance for north-facing points was generally higher on the south side of the highway, compared to the north side, except for points on the ridgeline running north of the site where light was reflected from exposed ground and vegetation (Figure 4B). Luminance for south-facing points was generally higher on the north side of the highway (Figure 4C).

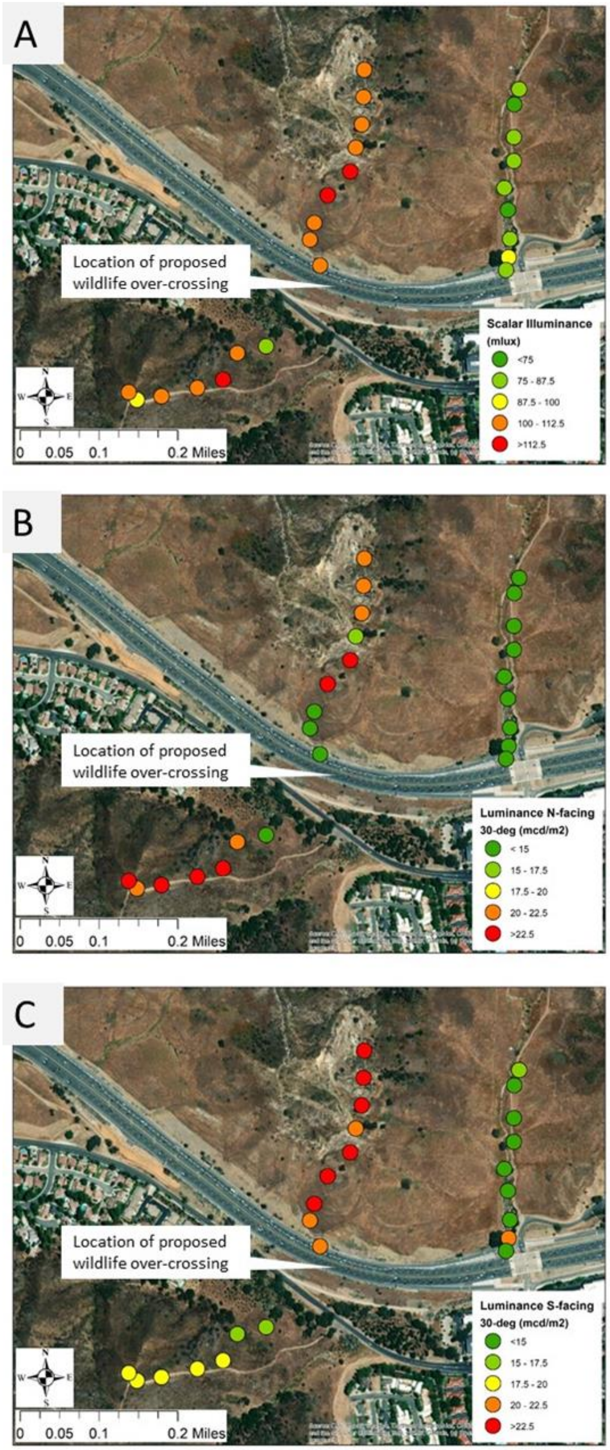

Figure 4. Light conditions along transects to the north and south of the proposed crossing site and along a creek bed east of the site, north of the highway. A) Scalar Illuminance (mlux); (B) Luminance (mcd/m2) facing north from each point; and (C) Luminance (mcd/m2) facing south from each point.

2. TOC

We also used field measurements of traffic noise and glare to create disturbance maps for the approach zone from the east to the proposed TOC site (Figure 5). Glare from traffic (Figure 5A) propagated through the roadside differently from traffic noise (Figure 5B). For example, gullies at the far northern and southern ends of the study area that were adjacent to the roadway, but lower elevation than the roadway, both had lower glare compared to other areas adjacent to the highway, but still had relatively high noise levels, >65 dBA.

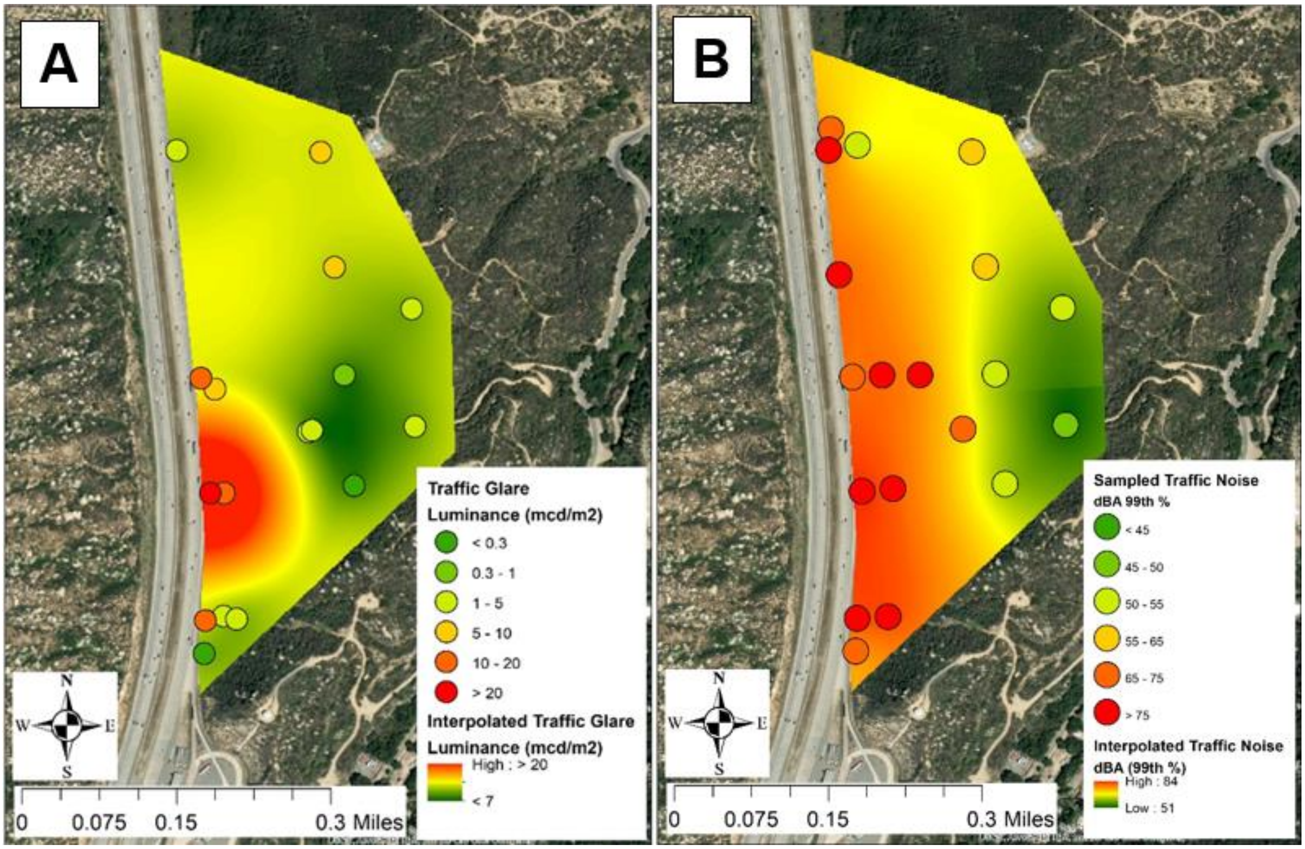

Figure 5. A) Field measured and interpolated traffic glare and B) field measured and interpolated traffic noise in the eastern approach to the TOC.

Approach Zone Designs

1. LCOC

We created 4 primary designs for the approach zone to the LCOC, including variations in noise barriers and berms. The first design can be thought of as a wildlife over-crossing design typical in most of the world, with little mitigation of traffic noise and glare (Figure 6A). The second design includes excavation (lowering) of the terrain on the north approach zone (tan area) and noise barriers adjoining the crossing structure (Figure 6B).

We termed the noise barriers "ha-ha walls," because we composed them of concrete walls with sloped fill on the side facing away from the highway. The third and fourth designs extend the second design and include two variations on disturbance-reducing berms with one large berm (Figure 6C), or three smaller berms that allow for water movement between the berms (Figure 6D).

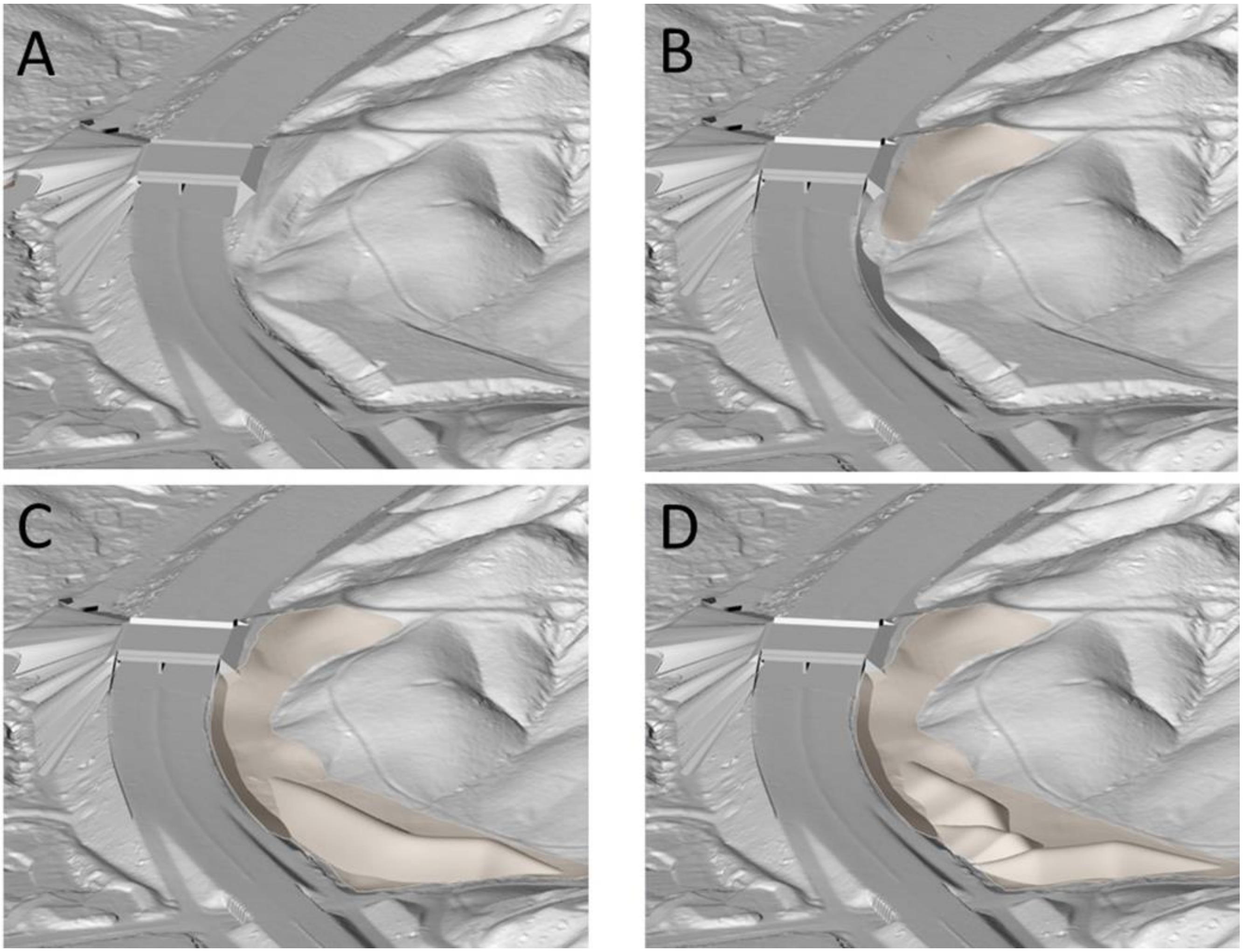

Figure 6. Designs for the northern approach to the LCOC: A) "typical" design (Design 1) for an over-crossing without noise and glare mitigation in the approach zones; B) Design 2 = Design 1 + modification of the immediate approach to the north (tan area) and addition of noise barriers along the highway; C) Design 3 = Design 2 + modification of the northern approach and addition of a large berm; and D) Design 4 = Design 2 + modification of the northern approach and addition of 3 berms.

2. TOC

We created three designs for noise/glare abatement for the TOC approach zones on both the west and east sides, each varying in the heights of the barriers, with 10-foot, 15-foot, and 20-foot barriers. The barriers extended to the north and south of the crossing structure on each side of the highway (Figure 7). The barriers on the west side of the highway were placed on top of an existing terrace which is about 20-30 feet above the roadway and is approximately the height of the proposed crossing structure. The barriers on the east side were above the existing gully to the north and on the side of the slope to the south of the structure.

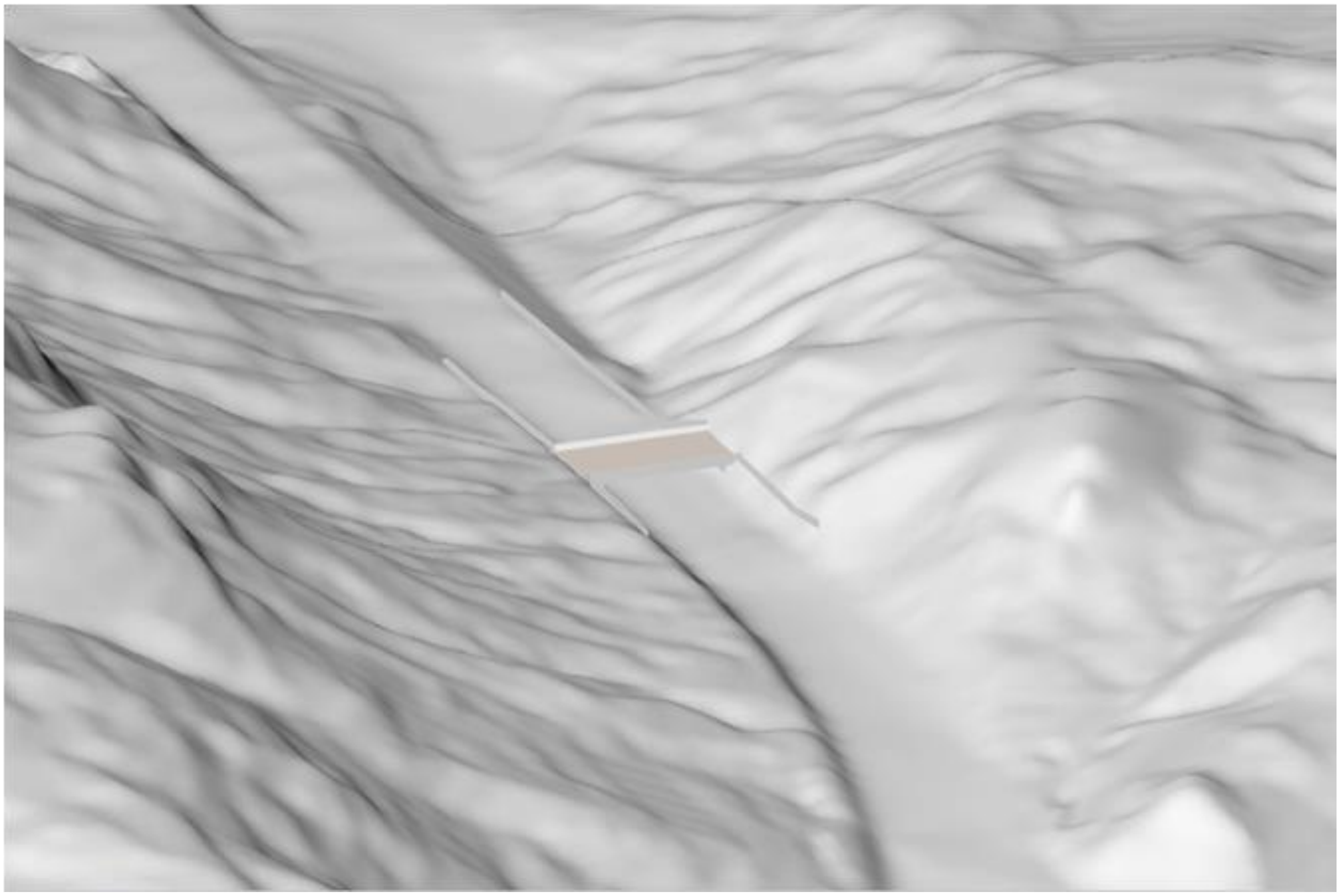

Figure 7. Designs for the approaches to the TOC: The bridge is tan and the barriers extend north and south along the roadway on either side of the road. The gully associated with the northeast approach to the crossing is visible above the bridge in the image.

Noise and Glare Reduction

1. LCOC

The designs varied in their reduction in traffic noise and glare, with noise barriers providing minimal reduction and berms having the greatest effect. We placed virtual "sample points" (Figure 8) representing an animal moving down the valley to the east of the crossing and across the crossing heading south (points 1–16, Figure 8). We also represented an animal moving north across the crossing from the south (points 23–17, Figure 8). The presence of noise barriers reduced modeled traffic noise intensity into the approach zone for both the north and south sides of the crossing structure (Figure 9). The area immediately adjacent to the proposed crossing structure location had modeled noise levels similar to those measured in the field (>65 dBA, Figure 9A).

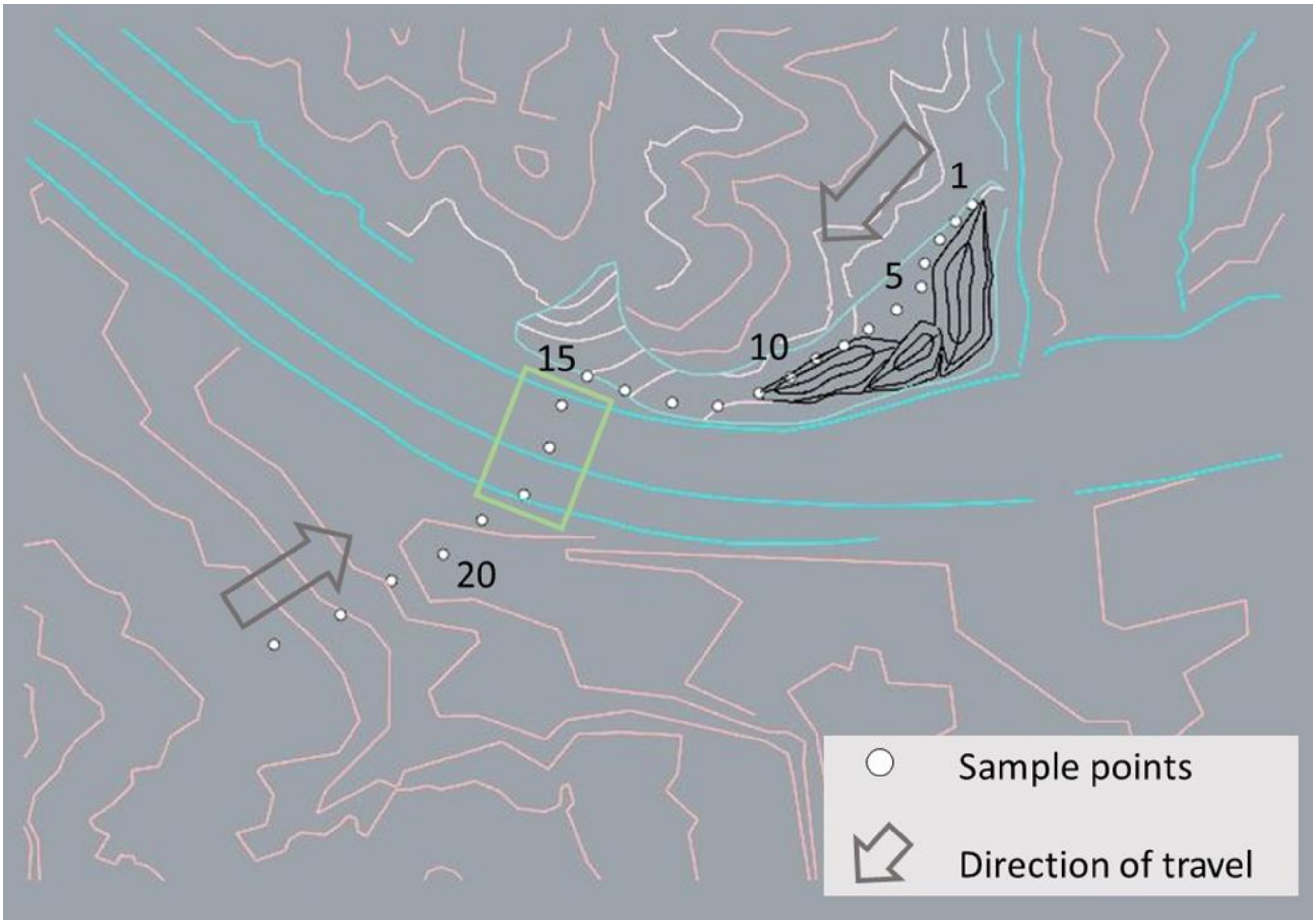

Figure 8. Locations of sample points for traffic noise and glare. The arrow indicates the direction of travel for a virtual animal. The dark pink lines represent topographical contours, and the aqua lines represent the edge of the roadway and ramps.

The bridge alone (with walls on the bridge) had noise levels that were relatively low (Figure 9B). However, the modeled noise in the approach to the over-crossing was only reduced with noise barriers (ha-ha walls, Figure 9C). The further addition of a berm, or three separate berms (Designs 3 & 4, Figure 6C, Figure 6D) resulted in modeled noise levels less than 65 dBA for most of the approach from the northeast.

An area at the western end of the berm design remained slightly noisy due to sound propagation from an elevated portion of the highway to the east. For the south approach zone, barriers were sufficient to reduce glare and noise (Design 2, Figure 6B).

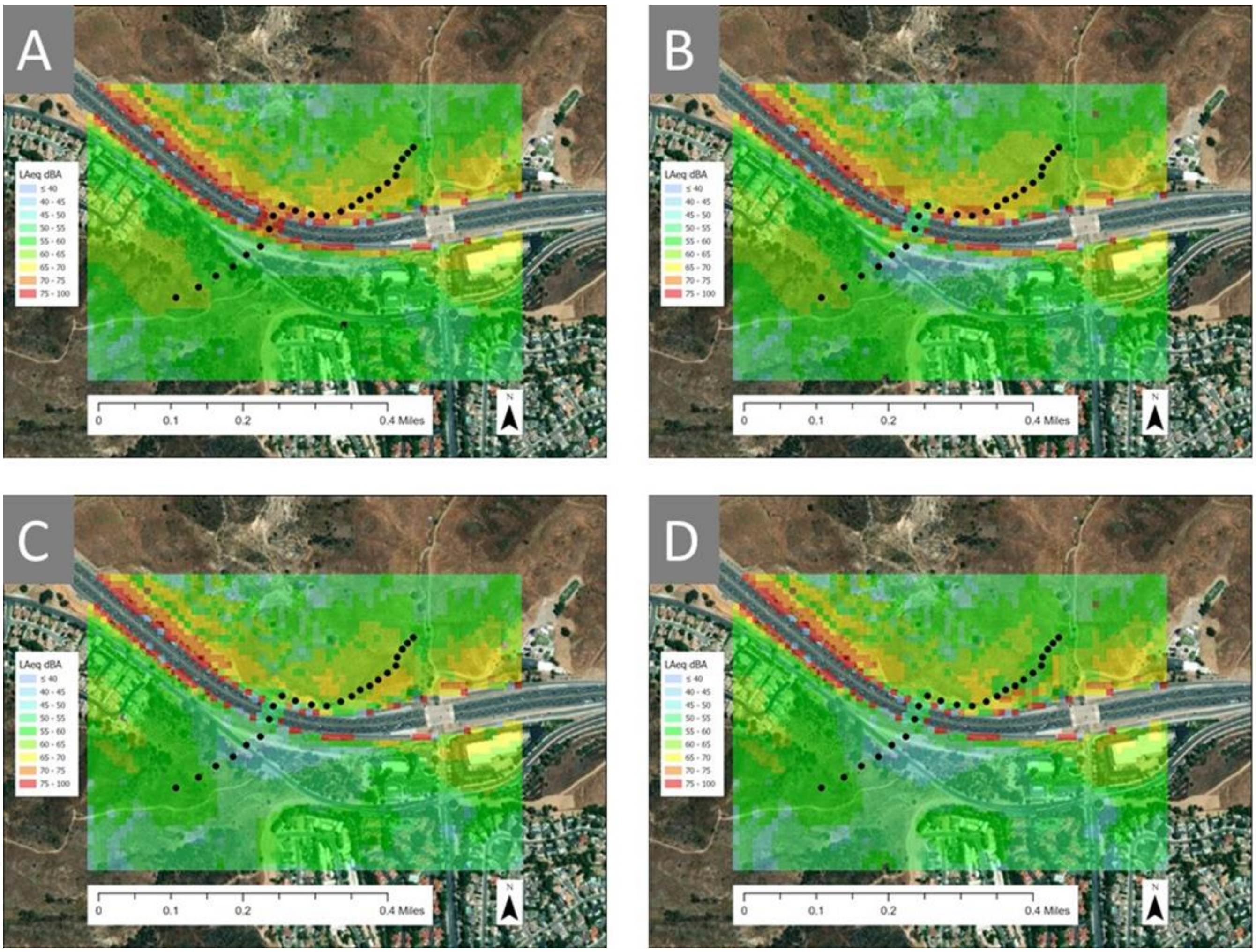

Figure 9. Results of traffic noise modeling for the LCOC and approach zones. A) Original terrain, B) Original terrain + crossing structure with barriers on the structure (Design 1); C) Modified terrain + crossing structure + noise barriers (Design 2); and D) Modified terrain + crossing structure + noise barriers + three berms (Design 4).

We evaluated the change in traffic noise and glare (Figure 10) at each sample point with the different designs. The presence of a berm in the north approach zone (Design 3 or 4, Figure 6C, Figure 6D) reduced noise significantly compared to walls alone (Figure 10A). Noise barriers (Design 2) reduced noise compared to the absence of noise barriers (Design 1), but noise was still greater than the designs with berms (3 and 4, Figure 10A). Similarly, a berm in the approach zone (Design 4) resulted in greater improvement (reduction) in traffic glare than barriers alone (Design 2, Figure 10B).

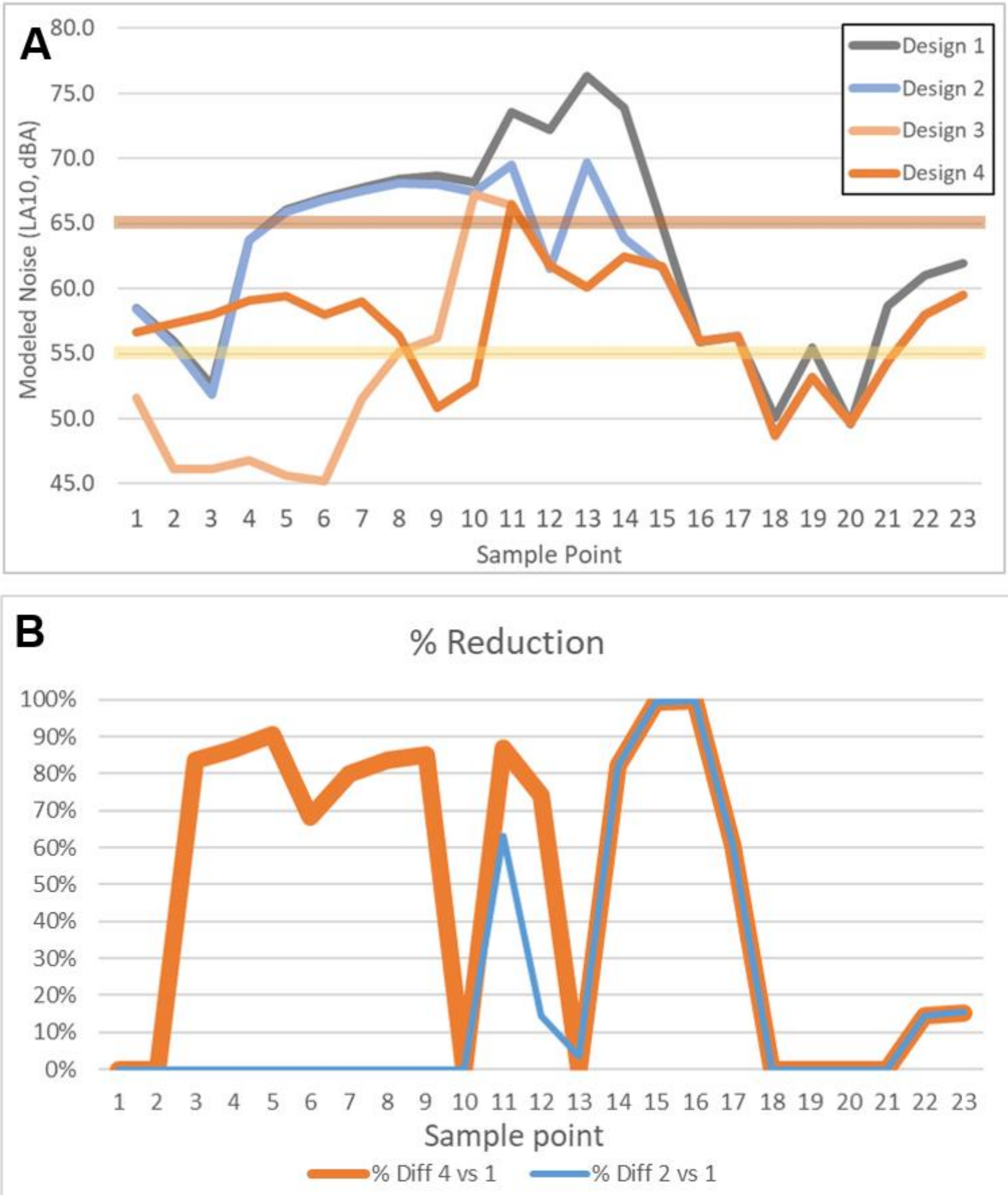

Figure 10. A) Traffic noise for Designs 1, 2, 3 and 4 relative to design thresholds of 55 dBA and 65 dBA; and B) Difference in traffic glare between Designs 4 and 1 (orange line) and Designs 2 and 1 (blue line).

2. TOC

Because of potential on-site limitations for large berms at this site, we used model barriers to reduce noise and glare in the immediate approach zone to the crossing. As with LCOC, we placed virtual "sample points" (Figure 11) representing an animal moving from the east of the crossing and across the crossing heading west (points 17–21,Figure 11).

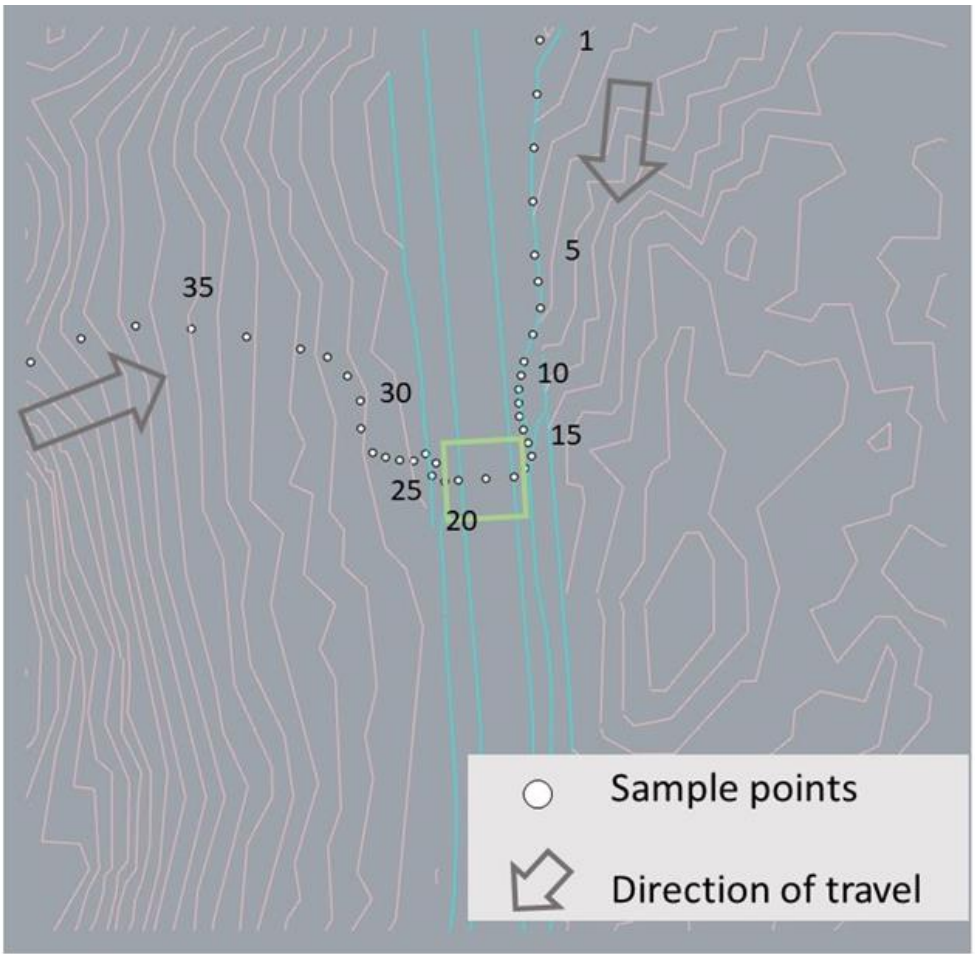

Figure 11. Locations of sample points for traffic noise and glare at the TOC. The arrow indicates the direction of travel for a virtual animal. The dark pink lines represent topographical contours and the aqua lines represent the edge of the roadway and ramps.

The presence of noise barriers reduced traffic noise intensity into the approach zone immediately adjacent to the crossing structure (Figure 12). Unsurprisingly, the reduction was greater with higher walls. For example, with 20 foot-tall walls, a relatively large proportion of the approach zones to the crossing had noise levels <65 dBA (Figure 12D). The area immediately adjacent to the proposed crossing structure location had modeled noise levels similar to those measured in the field (>65 dBA, Figure 8A). The bridge alone (with walls on the bridge) had noise levels on the bridge that were relatively low (Figure 12A). However, the modeled noise in the approach to the over-crossing was only reduced with noise barriers (Figure 12B). An area at the eastern side of the crossing remained slightly noisy due to noise from more elevated portions of the highway to the south. For the west approach zone, barriers were sufficient to reduce noise, with higher walls leading to a larger area with reduced noise (Figure 12 B-D).

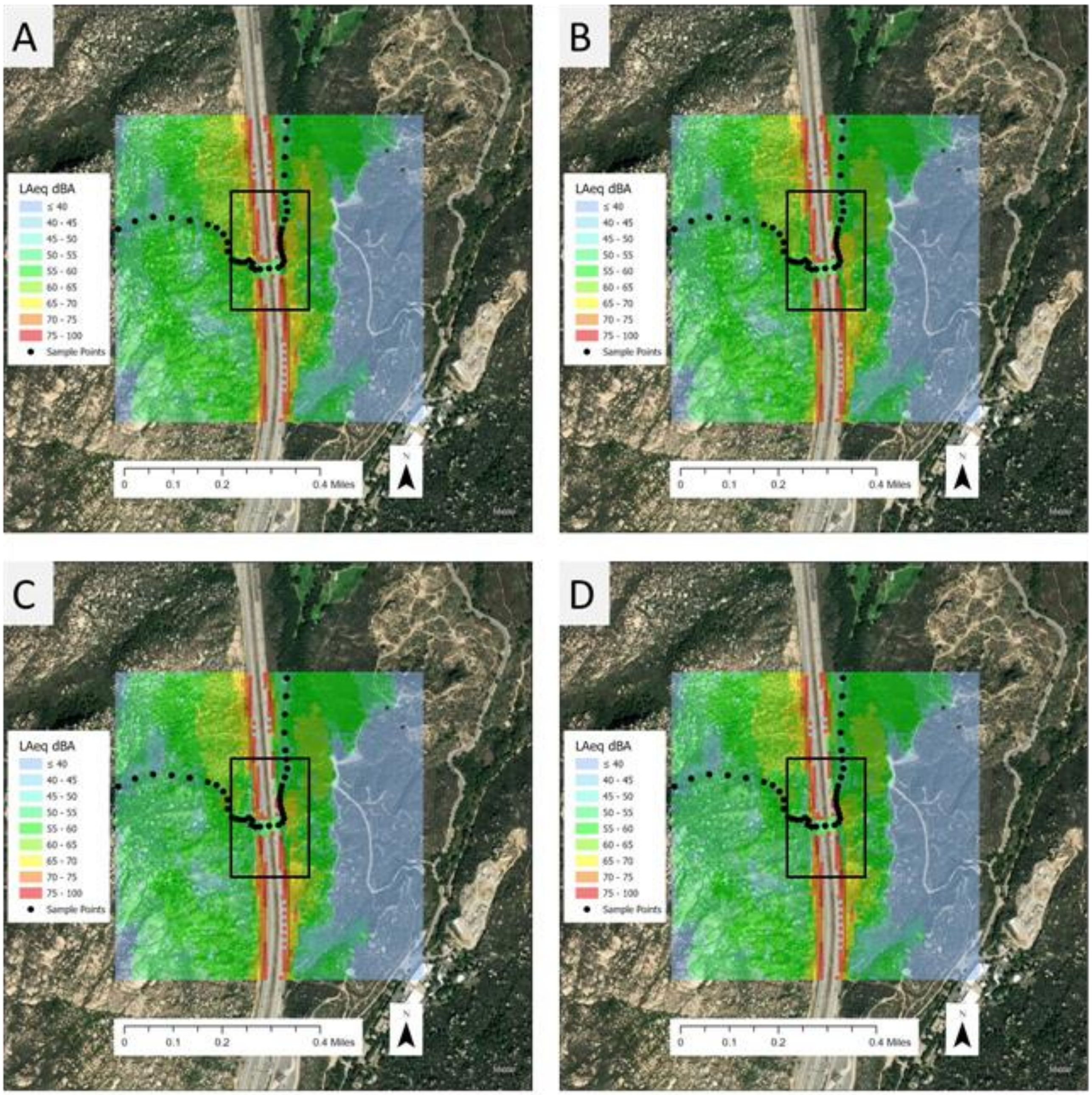

Figure 12. Results of traffic noise modeling for the TOC and approach zones. A) Original terrain + crossing structure with walls on the structure; B) Crossing structure + 10-foot tall noise barriers; C) Crossing structure + 15-foot tall noise barriers; and D) Crossing structure + 20-foot tall noise barriers.

We evaluated the change in traffic noise (Figure 13) at each sample point with the different barrier heights. The presence of a barrier in the immediate approach zones (sample points 10–17 and 22–28) reduced noise compared to no barrier (Figure 13). Higher noise barriers (e.g., 20 ft walls) reduced noise more than lower barriers (e.g., 10 ft walls). The most critical portion of the approach zone is immediately adjacent to the entrance to the crossing structure where noise levels from traffic are the highest. Noise levels for all barrier designs were >65 dBA in the approach area immediately adjacent to the east end of the crossing (red box area in Figure 13).

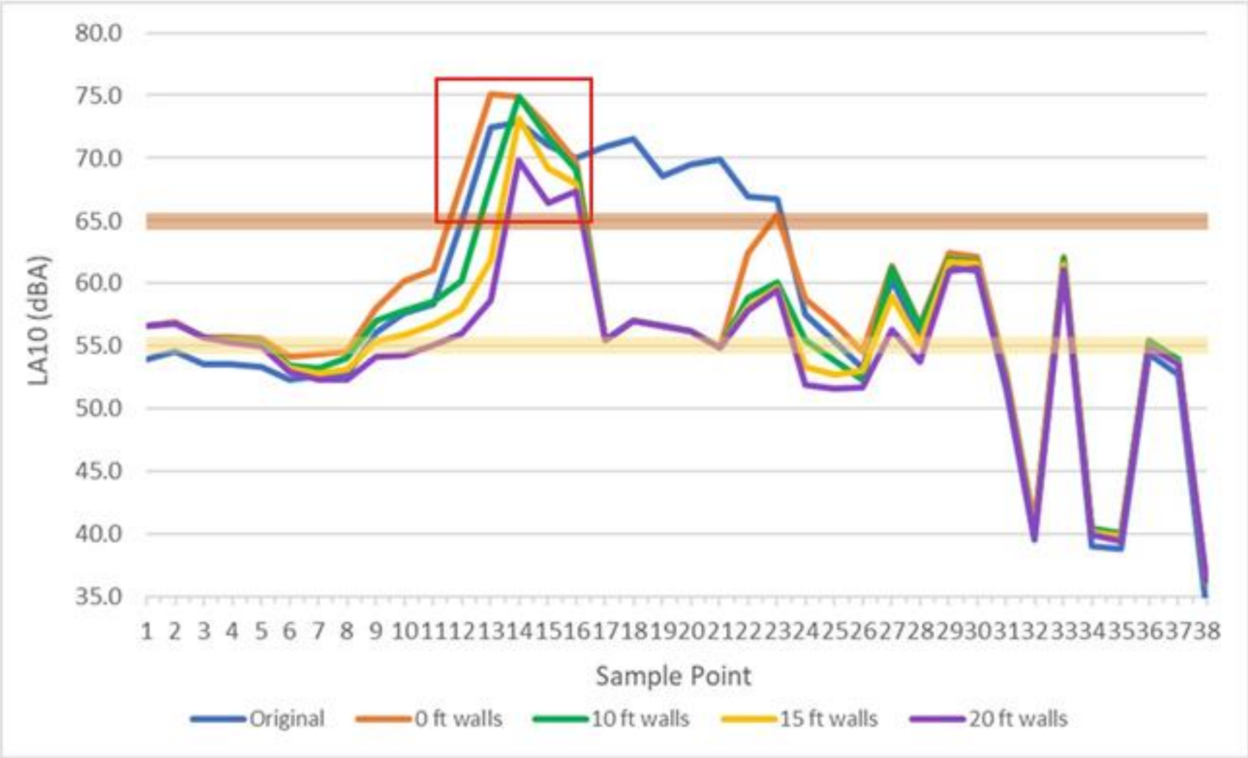

Figure 13. Traffic noise for the original landscape and highway (blue line), the original landscape, highway and crossing structure (0 ft walls, orange line), and three barrier heights: 10 ft walls, green line, 15 ft walls, orange line, and 20 ft walls, purple line. The red box highlights part of the approach zone on the east side where the bridge structure would connect with the gully to the northeast of the proposed site.

Designing Approach Zone "Dark & Quiet Paths"

The design approach we used was iterative, meaning that we used learning from the glare and noise modeling to modify the model designs. The design approach was to create "dark and quiet paths" for wildlife movement through excavation, berms, and walls in various combinations. For LCOC, we basically created virtual valleys behind a line of artificial hills to mask traffic noise and light in the hopes of creating a dark and quiet path. For LCOC, we were constrained by the volume of available material on site for the berms and by the height of noise barriers (maximum 20 feet). For TOC, local topography severely constrained the possibility of modifying the terrain in the approach zones to the crossing structure, meaning that noise barriers and positioning of the crossing relative to local gullies were the primary mitigation options for traffic disturbance. There are areas within both approach zones that could be topographically manipulated to reduce noise and glare, similar to the approach used for LCOC.

This iterative optimization approach could be used in other locations with similarly-modifiable landscapes. This could be used to model dark and quiet paths through otherwise noisy and bright landscapes to optimize potential wildlife movement to a crossing structure. If material is available on-site, the cost of moving it around will usually be dwarfed by the cost of the built structure. A caveat to this finding is that in the case of a deficit in available fill on-site, additional fill would have to be imported from outside the project area, which would increase costs. The balance then would be whether or not the additional cost to reduce traffic noise and glare for wildlife in the approach zone would improve the ecological functioning of the crossing structure.

Discussion

We quantified traffic noise and glare within the approach zones to two sites of proposed WCSs. We identified areas where excessive noise and glare could inhibit wildlife use, thus preventing them from accessing the WCSs. We used design software to modify land-forms within elevation models for each WCS area to reduce traffic noise and glare. We found that certain model variants were effective in reducing noise and glare to levels that could be tolerable to wildlife approaching the structures. The approach we used could be replicated for other proposed and existing WCSs, whether built for wildlife or incidentally used as such by moving wildlife.

The inclusion of structures that mitigate traffic noise and glare has the potential to improve wildlife use of crossing structures. The two case studies here showed how noise barriers and berms could reduce noise and glare in the approach zones to the crossing structures in locations where wildlife have been previously found to move (W Vickers and S Riley, personal communication). The LCOC is proposed to be the largest wildlife over-crossing in the world and to connect isolated mountain lion and other predator populations. The TOC is similarly proposed to connect isolated mountain lion populations, as well as being near a stretch of the interstate where there is a high density of mountain lion deaths from traffic. Both structures are in locations with very high traffic volumes and concomitant noise and glare propagation into nearby habitat. The ecological success of both structures will depend on how readily animals will traverse from adjacent habitats onto the crossing bridges. Mitigating disturbance of the approaches to the bridges is thus key to their success.

We described several commonly-used landscape design features (barriers and berms) that change noise and glare propagation in different ways. Previous research by us and others helped us to develop thresholds for wildlife-disturbance by traffic as guidance for performance of the structures (Shilling et al., 2018 & 2020). For LCOC, we found that a combination of barriers adjacent to the highway with berms at greater distances were likely to provide both functional reduction of traffic disturbance and contribute to a landscape aesthetic. This means that animals migrating from the north can follow relatively quiet (<65 dBA) and dark paths to the crossing structure, critical to it being a cost-effective investment in wildlife connectivity. For TOC, berms may be more difficult to implement, so we used noise barriers placed strategically to limit noise and glare propagation into the immediate approach zone to the crossing. We were not able to achieve the degree of modeled noise reduction as with LCOC (<70 dBA vs. <65 dBA), primarily due to topographical limitations on the site. However, we think further site manipulation is possible to achieve greater reduction. For example, with TOC we did not artificially modify the terrain near the crossing, which could be done to reduce noise and glare immediately adjacent to the structure.

An important potential limitation of the glare evaluation is that point sources of light in the landscape (e.g., buildings, streetlights) were not included. Only glare originating from vehicle headlights was modeled for the different scenarios. Because these landscape sources of light are already present, we considered them as existing disturbances to which wildlife may have already adapted. However, in highly-disturbed landscapes like that around LCOC, the non-vehicle sources of light could be more important for wildlife behavior and could also have mitigatable impacts.

Future Directions and Needs

There are three obvious next steps to wildlife-responsive design of crossing structures: 1) repeating the process at another location, 2) field-testing the noise and glare reduction by the mitigation structures and 3) testing whether or not wildlife respond positively to the design. For the first step, we welcome partnering with Departments of Transportation and others to model and design noise and glare mitigation into proposed crossing structures, or to improve conditions for existing crossings. Achieving the second and third steps will depend on post-construction monitoring, the wildlife portion of which is proposed to be carried out in the LCOC area by the National Park Service. By designing monitoring at a fine-enough scale, path selection by individual animals and species could be measured and response to noise and glare mitigation determined.

From the perspective of wildlife responses to anthropogenic noise and light, other next steps should address landscape disturbance in combination with traffic-generated noise and light. All wildlife crossing structures could be impacted by existing or newly developed sources of disturbance. Residential development of any density potentially includes street and building lights, human-related sounds, and traffic noise and light on adjacent streets. Modeling and mitigating noise and light disturbance of approaches to and passage through crossing structures should include these spatially relevant impacts.

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