Modeling and mapping hikers' exposure to transportation noise in Rocky Mountain National Park

By Logan Park, Steve Lawson, Ken Kaliski, Peter Newman, and Adam Gibson

NATURAL AND CULTURAL SOUNDS ARE INTEGRAL MEMBERS of the suite of resources and values that the National Park Service (NPS) is charged with preserving, restoring, and interpreting (NPS 2000). Results of research conducted in a variety of national park settings suggest that the quality of visitors' experiences is tied to the naturalness of the area's soundscape (Manning et al. 2006; Tranel 2006; Miller 2002). For example, findings from a recent study in Haleakala National Park in Hawaii suggest that the primary reason for visitors to take an overnight backcountry trip in the park is to experience the sounds of nature (Lawson et al. 2008). Human-caused sounds from aircraft, roads, maintenance activities, and other visitors, however, commonly permeate park soundscapes, making natural sounds and quiet an increasingly scarce resource (Krause 1999).

Recently, the National Park Service has applied indicator-based, adaptive management to address soundscape management and planning (Pilcher et al. 2008). This process involves formulation and long-term monitoring of soundscape indicators and standards of quality. Indicators of quality are measurable, manageable proxies for desired park conditions, and standards of quality are numerical expressions of desired conditions for indicators. As an example, the National Park Service might specify "human-caused noise-free interval duration" as an indicator of quality related to providing visitors opportunities to experience natural sounds and quiet. A standard of quality for this indicator might specify that at least 90% of visitors will experience at least one interval of 15 minutes or more that is free of human-caused noise while visiting the park.

Soundscape-related indicators and standards of quality are now being developed at a number of national parks, but measurement of some indicators, such as highly variable soundscape metrics, is nontrivial (Lawson and Plotkin 2006; Ambrose and Burson 2004). For example, natural sound levels fluctuate because of wind, air characteristics (e.g., density, temperature), and wildlife. Furthermore, visitors' exposure to natural and human-caused sounds is difficult to observe directly or measure through visitors' self-reports in surveys. However, visitor use and noise modeling technologies are potentially useful in this situation (e.g., Lawson and Plotkin 2006; Lawson 2006; Miller 2004; Roof et al. 2002).

The purpose of this article is to demonstrate the use of visitor use and noise modeling tools to provide spatially precise, integrated information about soundscape conditions within a national park setting. In particular, it presents research conducted at Rocky Mountain National Park, Colorado, to model and map visitors' exposure to transportation-related noise while visiting attractions and hiking on trails in the Bear Lake Road corridor. The results of this work are expected to provide the National Park Service with a monitoring tool to track soundscape-related indicators of quality in Rocky Mountain National Park that is adaptable to other national park units.

Methods

Study area

As noted, motor vehicles are one of the most common and widespread sound sources within national parks. Consequently, park soundscapes can be dramatically affected, both positively and negatively, by transportation planning and operations management decisions. The purpose of this project is to use noise and visitor use modeling to quantify and map the effects of shuttle bus service and private vehicle access management in the Bear Lake Road corridor on the park's soundscape. Furthermore, the project combines noise modeling outputs with visitor trip data to estimate the condition of potential soundscape-related indicators of quality.

Data collection

For the purposes of developing the transportation noise model and generating spatially precise estimates of visitors' exposure to noise from Bear Lake Road, four primary types of data were collected in Rocky Mountain National Park during summer 2008: (1) traffic volume by vehicle classification, (2) sound level data, (3) visitor hiking routes, and (4) daily visitation by trailhead. Continuous traffic counters were installed at three locations to measure directional traffic volumes at 15-minute intervals during a two-week period selected to represent the peak period of park visitation (fig. 1, next page).

Sound level data were collected at seven locations over an eight-day period during the park's peak period of visitation (fig. 1). The acoustic monitoring locations were selected to represent a range of soundscape environments within a typical day's hike from trailheads along Bear Lake Road. For example, monitoring sites ranged

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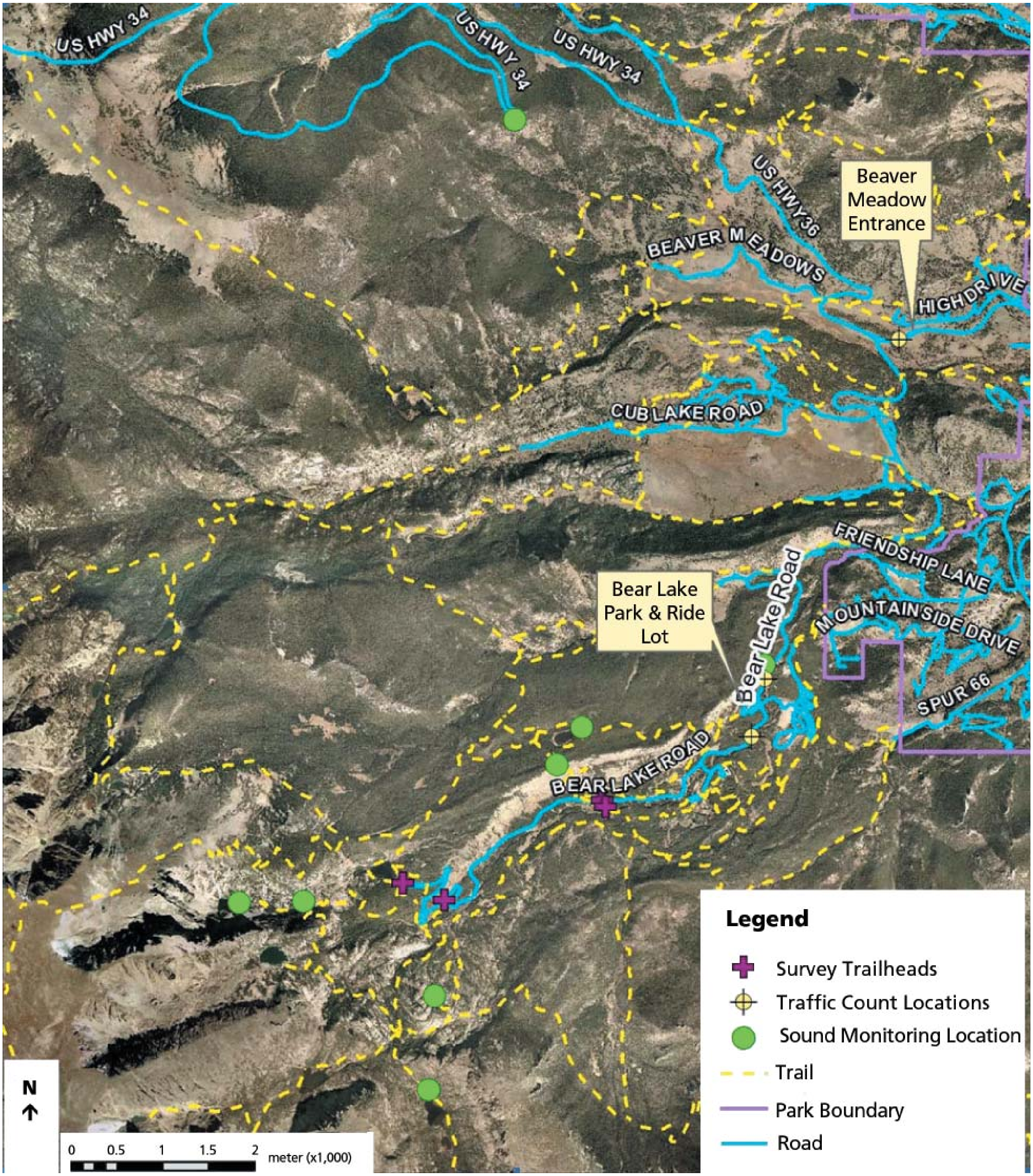

Figure 1. Study area, including traffic volume, sound level, and GPS-based hiking route monitoring locations.

from a roadside pullout at a scenic overlook to an alpine lake 1,800 meters (5,906 ft) from the road. To collect data needed to calibrate the transportation noise model directly to traffic volumes, one of the sound level meters was collocated within approximately 55 meters (60 yd) of the traffic counter installed north of the park-and-ride lot. All eight acoustic monitors were configured to record a sound level measurement at one-second intervals, and four of the monitors were also programmed to record one-third-octave band sound levels. All the sound level meters were calibrated prior to and after sampling using a handheld calibrator.

Visitor hiking routes data were collected on 13 sampling days between 31 July and 14 August 2008 via administration of Global Positioning System (GPS) units to visitors at four trailheads along the Bear Lake Road corridor (i.e., Bear Lake, Bierstadt Lake, Glacier Gorge, and Storm Pass). The GPS units were distributed to randomly selected visitor groups at the start of their hikes and collected at the end of hikes. Daily trailhead visitation was measured with mechanical trail traffic counters, calibrated with data from direct observation (Kiser et al. 2007).

Noise modeling and mapping

Sound propagation modeling of the traffic noise data was conducted using Cadna/A software made by Datakustik GmbH. The geographic scope of the noise model is a 14,000-by-14,000-meter (45,934 by 45,934 feet) square, with its northeast corner just north of the park entrance and east of the eastern park boundary. The model incorporates traffic volumes for the full extent of Bear Lake Road, as recorded by the automatic traffic counters. A digital terrain model was obtained from the U.S. Geological Survey and converted into elevation contours to model the attenuation of roadway sound due to intervening terrain. Propagation algorithms found in the German RLS-90 standard are used within the software to model how vehicle sounds from the Bear Lake Road permeate the surrounding landscape (Kaliski et al. 2007). In particular, the model estimates how sound propagates from the roadway to "receiver locations" specified by the model developer, taking into account intervening terrain, absorption of sound by the ground, energy losses into the atmosphere, and losses due to geometric spreading of the sound wave emanating from the road. In this study, sound pressure level (i.e., decibel) estimates were generated for a grid of 492,000 receivers covering every 20 meters (66 ft) within the study area. The result is a grid of daytime (6:00 a.m. to 6:00 p.m.) average sound levels representing traffic sound conditions during the sampling period. The grid data were then plotted for visual display via a noise contour map to depict the study area's soundscape conditions with respect to noise from Bear Lake Road.

Visitor use and noise exposure modeling

The GPS tracks of visitor hikes were imported into a geographic information system (GIS) environment for error correction and analysis. The data were filtered for positional inaccuracies due to poor satellite constellations and signals interrupted by high mountain peaks. Trip data split across multiple GPS files were assembled into individual trips, and trip attributes, including hiker movement speed, initial trailhead, and intended destination, were joined to the track spatial data.

Spatial statistics tools in the GIS software were used to estimate the amount of time and distance visitors must hike from trailheads to experience alternative soundscape conditions. Estimates were also generated for the proportion of visitors who experience at least 15 minutes of natural sounds and quiet. At the time of the study, the National Park Service had not defined a threshold for road noise beyond which natural sounds and quiet are compromised. Thus, a range of example road noise thresholds were evaluated to estimate the proportion of visitors who experience at least 15 minutes of natural sounds and quiet. The example road noise thresholds used in the analysis include ≤25 dB(A) (nighttime ambient natural sound level measured in the study), ≤30 dB(A) and ≤35 dB(A) (daytime ambient natural sound levels), and ≤65 dB(A) (the level at which noise interferes with conversational tones).

Results

Results of counts conducted to measure daily visitation, by trailhead, suggest that the Bear Lake Trailhead receives the vast majority of visitor use in the study area (table 1). The noise map, developed on the basis of Bear Lake Road baseline traffic conditions, in figure 2 (next page), depicts higher (louder) transportation sound pressure levels in warmer color tones and lower (softer) sound pressure levels in cooler tones. Further, the noise map depicts more heavily visited trail segments with thicker brown lines, and lesser-used trail segments with thinner brown lines. This map suggests that transportation sounds from Bear Lake Road perme-

Table 1. Study area visitation by trailhead, Rocky Mountain National Park

Trailhead	Average daily visitation	Proportion of total visitation
Bear Lake	7,353	89.1
Bierstadt Lake	96	1.2
Glacier Gorge	638	7.7
Storm Pass	170	2.1
Total	8,257	100.0

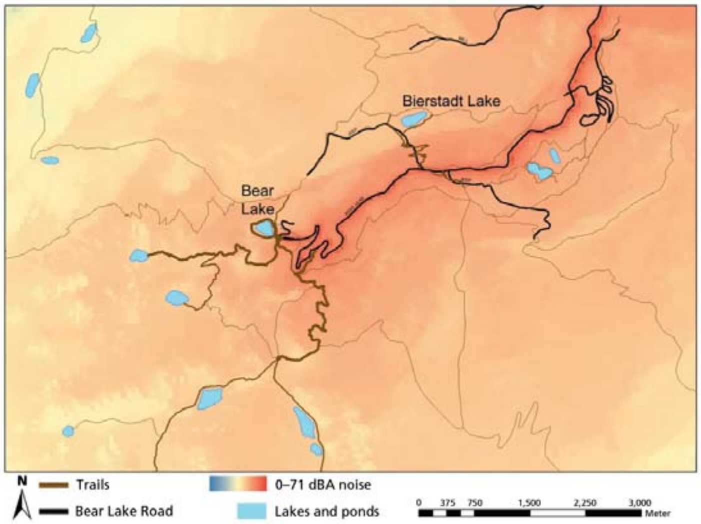

Figure 2. Noise map of baseline traffic volumes on Bear Lake Road and relative intensity of hiking use on adjacent trail network.

ate the park's soundscape throughout the adjacent trail system. The noise is concentrated along the road and falls off sharply with distance. However, the extent of noise in the area requires effort on the part of visitors to reach areas of natural quiet away from Bear Lake Road. For example, model results suggest that visitors following the most direct routes to natural quiet would have to walk more than 1,000 meters (0.6 mile) from all four trailheads in the study area to reach natural quiet as defined by areas of the park with road sound levels that do not exceed 25 dB(A) (table 2). Further, results in table 2 suggest visitors would have to walk more than 1,000 meters (0.6 mi) from two of the four trailheads in the study area to reach areas of the park with road sound levels less than 35 dB(A).

Summaries of the GPS track data indicate that visitors' average hiking speed is 0.55 meter/second (1.2 mph). This hiking speed is somewhat lower than typical average hiking speeds for other areas (van Wagtendonk and Benedict 1980; Bishop and Gimblett 2000), because of many groups' propensity to linger or move more slowly around attraction areas such as Bear Lake and because of the relatively steep topography in the study area. This hiking rate, coupled with the hiking distance results, suggests that visitors would have to hike between 6 and 51 minutes, depending on the trailhead selected, to reach natural quiet defined by areas of the park where road sound levels are ≤30 dB(A), or in some cases would never reach it (table 3). As expected, the estimated travel times to reach natural quiet reported in table 3 vary according to the road noise threshold used to define areas of natural quiet and sounds. Minimum distance to natural quiet varies across the trailheads in the study area by a factor of nearly 10, suggesting opportunities for management to highlight specific trails to visitors that provide greater opportunities for natural sounds and quiet.

Table 2. Hiking distance from trailhead required to reach closest natural quiet*

Trailhead	Noise threshold / Distance (m)			
	25 dB(A)	30 dB(A)	35 dB(A)	65 dB(A)
Bear Lake	1,093	206	155	0
Bierstadt Lake	1,934	1,586	1,542	23
Glacier Gorge	2,097	1,682	1,210	0
Storm Pass	1,907	1,376	973	0

*Natural quiet is defined as sound levels below noise thresholds.

Table 3. Average hiking time from trailhead required to reach closest natural quiet*

Trailhead	Noise threshold / Travel time (minutes)			
	25 dB(A)	30 dB(A)	35 dB(A)	65 dB(A)
Bear Lake	33.1	6.2	4.7	0.0
Bierstadt Lake	58.6	48.1	46.7	0.7
Glacier Gorge	63.5	51.0	36.7	0.0
Storm Pass	57.8	41.7	29.5	0.0

*Natural quiet is defined as sound levels below noise thresholds.

Table 4. Percentage of hiking time visitors experience natural quiet*

Trailhead	Noise threshold / % of hiking time			
	25 dB(A)	30 dB(A)	35 dB(A)	65 dB(A)
Bear Lake	54.5	68.8	77.8	100.0
Bierstadt Lake	12.1	40.1	43.7	100.0
Glacier Gorge	60.2	62.9	74.1	100.0
Storm Pass	0.6	20.1	39.5	100.0
Study area–wide	53.8	63.6	73.2	100.0

*Natural quiet is defined as sound levels below noise thresholds.

The time and distance required to reach natural quiet defined by road sound levels ≤30 dB(A) may present difficulty for less mobile visitors seeking to get away from the transportation noise associated with the road. However, using the 30 dB(A) noise threshold for analysis, the results suggest that, on average, visitors spend a majority (63.7%) of total hiking time in natural quiet (table 4). By contrast, visitors walking from Storm Pass or Bierstadt Lake trailhead will experience elevated levels of noise for most or all of their hike, while visitors starting from Bear Lake trailhead and hiking to more distant lakes (e.g., Emerald Lake or Nymph Lake) will experience almost uninterrupted escape from road sounds. The prevalence of opportunities to experience natural quiet is also sensitive to the manner in which natural quiet is defined. For example, "natural quiet," defined as soundscape conditions in which roadway sound levels do not exceed 65 dB(A), is experienced by virtually all visitors in the study area.

Table 5. Percentage of visitors who experience at least 15 minutes of natural quiet*						
	Noise threshold / % visitors					% of total hikers for all trailheads
Trailhead	25 dB	30 dB	35 dB	65 dB	n	
Bear Lake	26.0	32.5	49.6	83.7	123	89.1
Bierstadt Lake	5.4	48.6	51.4	81.1	37	7.7
Glacier Gorge	45.3	55.7	59.4	85.8	106	1.2
Storm Pass	0.0	33.3	33.3	33.3	3	2.1
Total	24.1	34.1	49.6	82.6	269	100.1

*Natural quiet is defined as sound levels below noise thresholds.

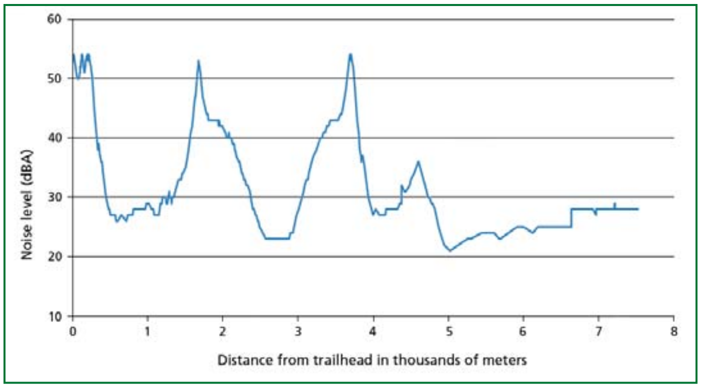

Figure 3. Noise level profile for hiking route from Bierstadt Lake trailhead, to and around Bear Lake.

With respect to assessing whether visitors are able to experience substantive "episodes" of natural quiet, results suggest that about half (49.6%) of visitor groups in the study area are able to do so for at least 15 continuous minutes, using 35 dB as the threshold for traffic noise (table 5). When examined by trailhead, the results provide further insight into visitors' soundscape experience and how it varies across the study area. Hikers near Storm Pass do not usually experience quiet for 15 continuous minutes (33.3% of groups), but almost double that proportion do along the Glacier Gorge Trail (59.4%).

Spatial modeling results also offer insights into how soundscape experiences evolve throughout the course of specific hiking routes. For example, the noise profile depicted in figure 3 is for a hiking route that begins at the Bierstadt Lake trailhead, travels to and around Bear Lake, and then heads into the backcountry. The hiker group embodied in these data experienced abrupt evolutions in their sound environment based on the hikers' route choices, encountering road noise at the trailhead (54 decibels), natural quiet on the way to Bear Lake (26 decibels), then additional road noise near Bear Lake (53 decibels).

Discussion and conclusions

By providing insights on the noise environment, use distribution, and route decisions of visitors in Rocky Mountain National Park, results from this study demonstrate the utility of integrated visitor use and noise modeling to support indicator-based adaptive management and monitoring of park soundscapes. Furthermore, these findings suggest how visitor use and noise modeling can be used to proactively and deliberately assess the effects of transportation planning and operations on park soundscapes. Subsequent analyses with the data and models presented in this article will be conducted to quantify and map the effects of potential modifications to the Bear Lake shuttle service and private vehicle access on soundscape conditions in the study area.

As the results of this work suggest, the modeling tools developed in this study can be used to estimate the conditions of soundscape-related indicators (e.g., percentage of visitors who experience at least 15 consecutive minutes of natural quiet) associated with baseline and alternative management scenarios. However, the National Park Service has not developed specific standards of quality for soundscape indicators in Rocky Mountain National Park. Formulation of empirically based standards of quality for soundscape indicators is recommended to complement the modeling tools developed in this study and to support indicator-based adaptive management of the park's soundscape.

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