Appendix A. Computer Model

A.1 Computer Model Overview

In determining the most appropriate way to model OSVs, the two primary models considered were the FHWA's TNM and the FAA's INM. Both models have been extensively validated[14, 27, 28, 29]. The TNM was designed for modeling noise in the vicinity of highways, while INM was designed for modeling noise in the vicinity of airports. Both models take into account sound attenuation due to diffraction over intervening terrain, but the ground-to-ground algorithms in TNM are considered more robust for modeling ground-to-ground propagation. So, TNM provides a solid foundation upon which to model OSVs, except for two issues. First, it is not capable of computing audibility, which is an important metric to the NPS. Therefore either sweeping changes to the TNM source code would be necessary, or audibility would have to be computed in post-processing, which would be cumbersome due to the large number of data points that would need to be evaluated for the two parks. Post-processing would also likely be error prone. Second, TNM is designed for relatively small-scale modeling scenarios, and using TNM over such a large geographic area would likely result in unacceptable runtimes.

The INM has been used to model noise in the national parks since about 1996[30]. The INM can be set up to produce results for contours, grids, and in tabular form. Beginning with Version 6.2, the INM is also able to calculate time audible, so minimal post processing was required. Further, it is a simple matter to import United Stated Geological Survey (USGS) terrain data into the INM. Version 6.2 could be easily adapted to model the more complex ground-to-ground propagation associated with OSVs.

The INM accepts as inputs: terrain data, ambient sound levels, source level as a function of distance, and operational data including vehicle tracks/paths, speeds, and number of operations. Terrain data is used to determine line-of-sight blockage and distances from source to receiver. Ambient sound levels are used to determine acoustic masking of sound sources (that is, audibility). The source level data are used to determine the sound source level based on vehicle operation and distance from the receiver. The tracks/paths determine the location of vehicles, while the number of operations and speeds determine how often a vehicle is present on a given segment and the time it is on the segment. If there are multiple operations for the same vehicle on the same segment at the same speed, the INM does not repeat the calculations but instead assumes identical results and combines the two in a manner appropriate for a given metric. For OSVs, the majority of these input data conform to a standard format. The one exception is source level as a function of distance. Normally, these relationships are developed as a function of engine power (for aircraft). For the current study of OSVs, these relationships were developed as a function of speed. For practical purposes, this is only a semantic distinction and has no side effects in the modeling.

Finally, it was deemed most appropriate to update the ground-to-ground propagation algorithm in Version 6.2 of the INM to better represent propagation of noise from OSVs over snow-covered terrain. This resulted in the inclusion of two new ground-to-ground attenuation relationships in INM, one for snowmobiles and the other for snowcoaches. Historically, the INM's ground-to-ground algorithm was based on empirical data, which is representative of acoustically soft ground (field grass) and aircraft sound sources. Since ground effects are dependent on source – ground – receiver geometry, source spectra, and ground cover, the standard INM ground-to-ground algorithm is not representative of OSVs or snow-covered terrain. In order to develop appropriate ground-to-ground algorithms for the current study, the physical acoustics algorithm of the TNM was utilized. The theoretical ground-to-ground attenuation were then averaged and regressions were developed.

One potential limitation of the INM for modeling audibility is that it treats the results from each operation as independent from all others. This means that the INM does not account for the fact that acoustic profiles of vehicles in close proximity with one another may overlap in time. If overlap does occur and if measured results are determined to be different for the case of overlapped profiles and non-overlapped profiles, then overlapping may need to be accounted for. One method of accounting for overlapping profiles is to conduct an extensive study of OSV operational patterns and to develop a curve fit to adjust the percent time audible results. A similar approach was taken for the Grand Canyon's tour aircraft overflights[14]. Another method of accounting for this would be to manually group simultaneous operations. For example, consider a group of ten snowmobiles in a guided group. Their one-third octave-band spectra could be summed across the vehicles creating a single source, which would then go through the operations as normal. This method is discussed in further detail in Appendix A.C.2.

A.2 Multi-Vehicle Ground Effects – An Enhancement to the Integrated Noise Model

When sound arrives at a receiver's position by a direct path and a path containing a ground reflection, the sound at the receiver is affected by the material properties of the ground at the reflection point. This ground effect can be modeled by using the material's effective flow resistivity[31]. Ground effects were determined for granular snow, 40 cgs rayls, and powdered snow, 10 cgs rayls. Because ground effects may be sensitive to source heights particularly when heights are close to the ground, these effects were determined separately for snowmobiles and for snowcoaches for each vehicle's one-third octave-band levels and source heights. The results were then averaged for each vehicle type. It can be seen from Figure 33 that there is a clear separation between the ground effects for snowmobiles and snowcoaches as evidenced by the fact that they are separated by more than two standard deviations of the estimated ground effects for the vehicles sampled.

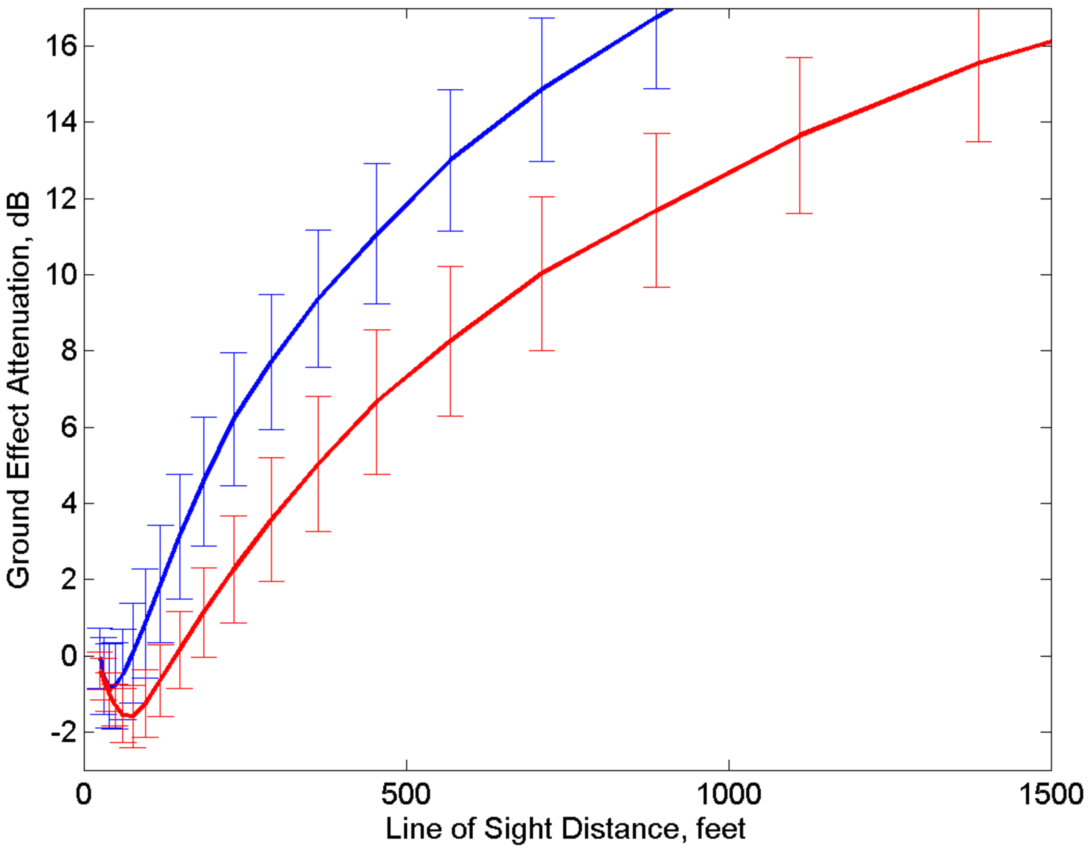

Figure 33: Comparison of ground effects for snowmobiles (blue) and snowcoaches (red). Vertical bars are +/- one standard deviation

A curve fit was developed to approximate these theoretical ground effects in the INM. The curve fit was chosen to be of the form:

$$GE(x)_{Vehicle,SourceHeight} = a\left(1-e^{-bx}\right)^3,$$

where x is in feet. Note, this is simply a first order system response raised to the third power to create an asymptotic approach to $x = 0$. A non-linear regression was used to determine the coefficients, *a* and *b*, in this function. Forty-five logarithmically-spaced distances between 25 and 5294 feet were used for the regression analysis. For snowmobiles, the final function was:

$$SM(x)_{1.5\,ft} = 14.41\left(1-e^{-0.006094\,x}\right)^3$$

and for snowcoaches the final function was:

$$SC(x)_{3\,ft} = 14.77\left(1-e^{-0.003224\,x}\right)^3$$

A comparison of theoretical ground effects and the INM regressions is shown in Figure 34. The two areas of deviation from the theoretical relationship occur near the source and far from the source. At distances very near the source, the theoretical ground effects indicate that there should be a slight increase in sound level due to the ground reflections. A satisfactory equation was not developed to model this behavior, however, at these close distances, the source will always be audible when present, so the effect of this shortcoming will be negligible. At far distances empirical evidence indicates that ground effects asymptote to approximately 12 to 20 dB[32]. In the INM, the limit is 13.86 dB. This is shown as the dashed line in Figure 34. It can be seen that the regression does follow the theoretical ground effects up to this limit.

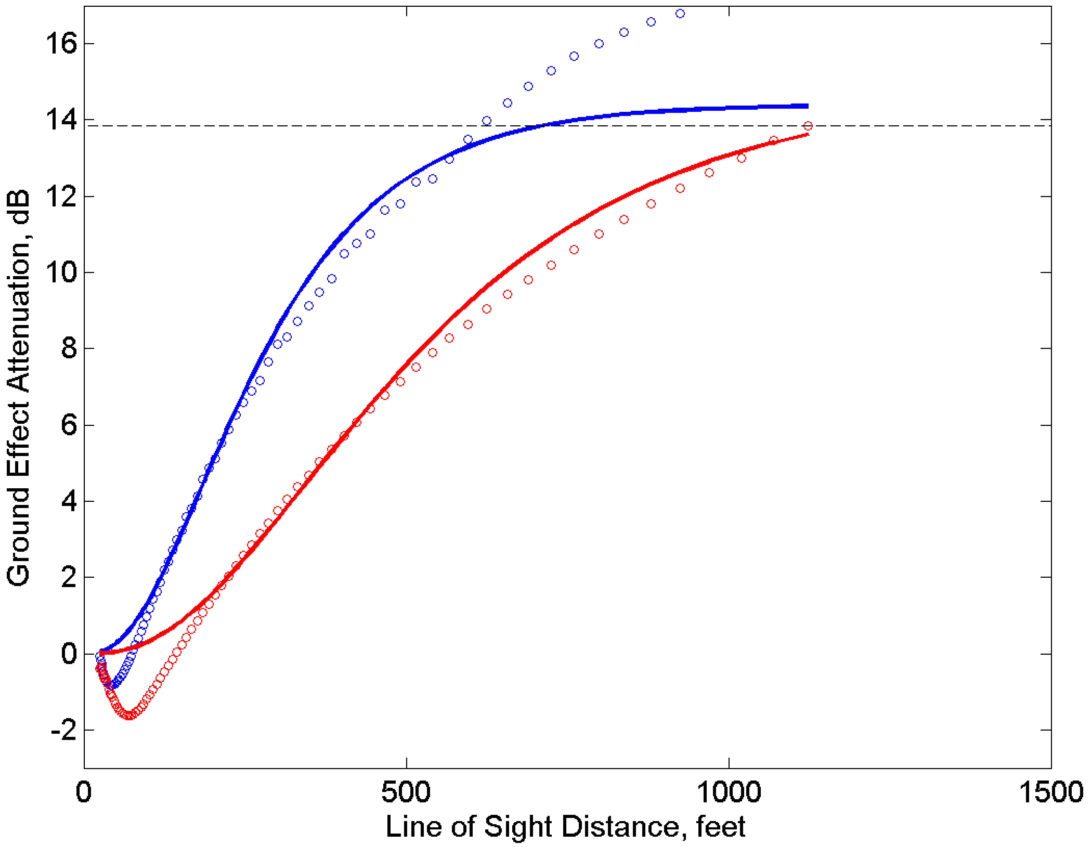

Figure 34: Ground effects for granular snow, 40 rayls, for snowmobiles (blue) and snowcoaches (red). Receiver is at 4 feet. Lines are curve fits. Circles are theoretical ground effect predictions. Dashed line is the Integrated Noise Model's hard coded limit on attenuation due to ground effects

Appendix B. Ambient Measurements

B.1. Site Locations

Table 14: Ambient measurement sites in Yellowstone

Description	Latitude (deg)	Longitude (deg)	Elevation (feet)
Old Faithful Weather Station	44.45688	110.83178	7400
Old Faithful Upper Basin	44.46325	110.82740	7400
Lone Star Geyser	44.41930	110.80482	7700
Mary Mountain Trail 1000 (feet)	44.56947	110.81088	7240
Mary Mountain 4000 (feet)	44.57433	110.80228	7236
Mary Mountain 8000 (feet)	44.58153	110.78603	7200
West Yellowstone 3.1 (miles)	44.65060	111.02554	6700
West Thumb	44.41589	110.57093	7900
Madison Junction: 2.3 (miles)	44.64253	110.89645	6800

Table 15: Ambient measurement sites in Grand Teton

Description	Latitude (deg)	Longitude (deg)	Elevation (feet)
Jackson Lake South Landing[a]	43.82221	-110.62323	6775
White Grass Ranch	43.65477	-110.76902	6680
Jackson Lake Cow Island	43.93135	-110.64674	6775
Jackson Lake Catholic Bay	43.85165	-110.59328	6800

B.2. Measurement System Noise Floor

The estimated natural ambient sound levels in Yellowstone and Grand Teton are low relative to the noise floors measured by using the system with a microphone simulator. See Figure 35 and Figure 36 for representative level differences between measured and instrument noise levels. Ideally the measured levels should be at least 10 dB greater than the instrument noise floor in order to assure that the instrument noise floor's contamination to the measured level is negligible. In several measured one-third octave-bands, the levels are quite close to the instrument noise floor. However, this is not a significant problem for the current modeling for several reasons. Audibility is driven primarily by low frequencies, which do not attenuate as quickly as high frequencies over distance. Since at the low frequencies, the signal-to-noise ratios of the ambient data are greater than 10 dB (with the exception of the 50 Hz band for open natural ambient), their estimates will not be affected by the noise floor. The lowest one-third octave-bands of the open natural ambient are within 10 dB of the noise floor, however, at these low frequencies the auditory systems noise floor will dominate the audibility calculation. If the ambient sound level is less than the Equivalent Auditory System Noise (EASN), then the equivalent auditory system noise is used in the determination of audibility[14]. It can be seen from Figure 37 that at most frequencies the equivalent auditory system noise will dominate the masking pattern involved with the audibility metric. That is, the equivalent auditory system noise will act as the masker in much of the audibility calculations.

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[a] Measured by using a low noise system.

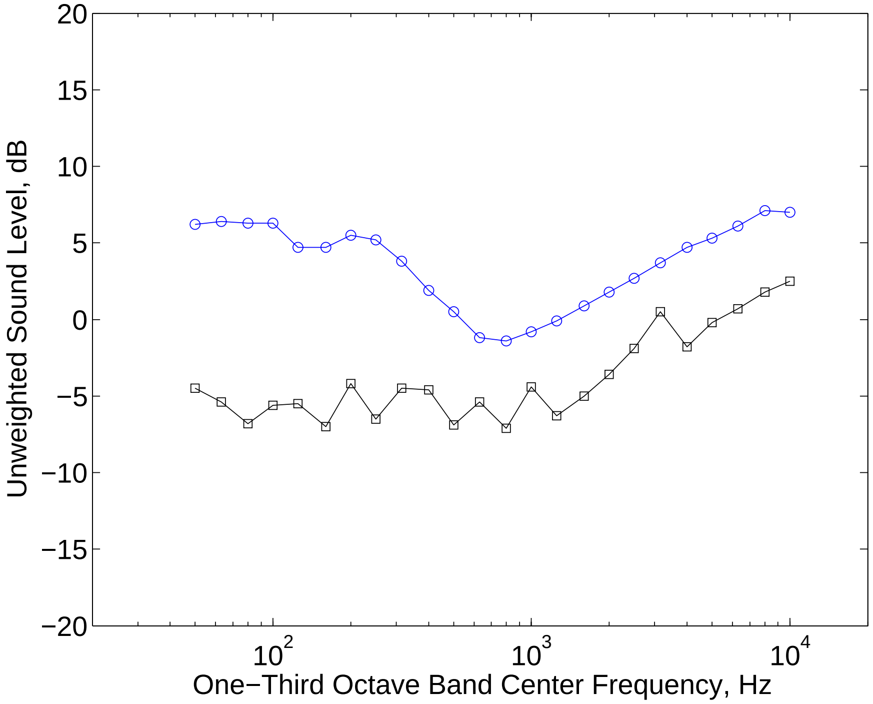

Figure 35: Comparison of forested natural ambient (L_{90}) and noise floor measured using microphone simulator. □ – Instrument noise floor, ○ – Estimated ambient.

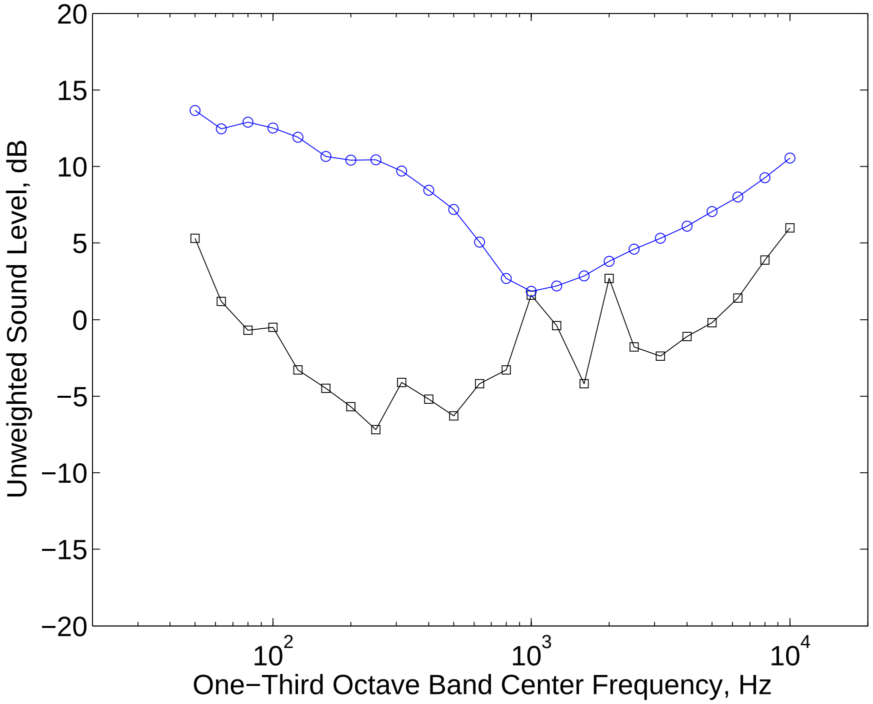

Figure 36: Comparison of open natural ambient (L_{90}) and noise floor measured using microphone simulator. □ – Instrument noise floor, ○ – Estimated ambient.

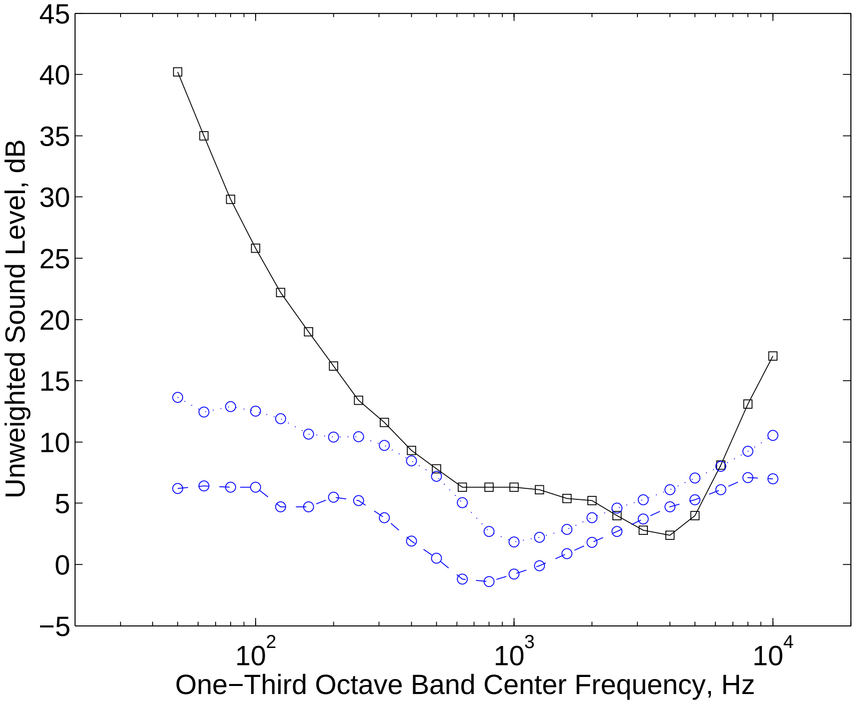

Figure 37: Comparison of natural ambient and threshold of human hearing for Yellowstone and Grand Teton National Parks. □ – EASN, ○ (···) – Open ambient, ○ (- -) – Forest ambient.

Appendix C. Sound Sources

C.1. Spectral Class Data and Noise-Speed-Distance Relationships

The data in Table 16 are derived from Reference 9 except for the full-track BAT. These one-third octave-band levels are based on numerous averages of vehicle pass-bys for speeds ranging from 30 to 40 miles per hour for snowmobiles and 20 to 30 miles per hour for snowcoaches. The data in Table 16 were used in developing ground-to-ground attenuation curves where the aggregate spectral shapes were most important. The one-third octave-band levels in Table 17 are derived primarily from Reference 8, which had more clearly defined speeds for each data set. Because the data in Table 17 had more clearly defined speeds, they were used to develop the relationship between speed and sound level. The data in Table 17 are shown graphically for two-stroke snowmobile, four-stroke snowmobile, Bombardier, Mattrack, and Snow Buster in Figure 41 to Figure 45.

After the 2005-2006 winter season, the National Park Service provided updated L_{Amax} measurements for four-stroke snowmobiles at 50 feet. Fifteen measurements of four-strokes were made at 15 mph with an average level of 64.7 dB(A). Fifty-four measurements were made at 30 mph with an average level of 71.4 dB(A). Eighteen measurements were made at 40 mph with an average level of 71.5 dB(A). Because these measurements covered a greater speed range, were more current than previous four-stroke measurements (2006 compared to 2000), and since four-strokes are being used to model BAT, the levels in the NSD relationships, Table 3, have been updated so that levels at 50 feet for four-strokes match those measured during the 2005-2006 winter season, see Figure 19.

Table 16: One-third octave-band levels used for developing snow covered ground-to-ground attenuation and spectral classes

Veh./OB Center Freq	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
Arctic Cat 1 (SM4)	47.0	50.9	56.6	53.3	66.1	58.4	65.6	67.8	56.8	70.5	68.8	62.0	56.5	58.6	57.6	58.1	60.4	56.8	55.3	52.0	49.9	47.0	44.2	41.7
Frontier (SM4)	47.8	51.6	75.6	56.0	56.1	71.6	62.4	65.8	61.6	68.9	65.2	59.9	58.9	59.4	56.2	58.7	60.7	58.4	58.2	58.6	54.3	51.6	46.6	42.4
Arctic Cat 2 (SM4)	54.8	54.0	57.6	57.6	62.2	68.9	59.1	66.8	71.1	63.5	65.9	69.1	61.4	59.0	62.2	61.8	62.7	62.2	60.2	55.3	52.9	51.0	48.8	45.6
Polaris (SM4)	49.6	49.7	67.3	75.6	60.0	61.2	65.4	64.5	66.2	64.1	63.6	63.7	59.5	58.0	61.1	60.4	61.7	61.3	58.5	58.1	55.3	52.4	48.6	44.5
Arctic Cat 3 (SM4)	52.0	51.7	57.5	54.4	69.4	61.6	58.6	64.9	68.5	64.5	64.9	64.9	59.4	57.4	60.3	59.8	59.9	60.3	58.1	56.1	54.6	53.3	50.1	46.1
Polaris 550cc (SM2)	50.0	50.9	49.7	52.5	54.1	56.0	64.8	66.1	59.2	60.4	67.5	58.5	61.8	66.0	62.5	65.1	67.1	64.5	60.3	58.8	57.3	52.4	50.1	46.8
Polaris 500cc (SM2)	48.0	49.1	51.9	61.5	55.7	55.4	71.9	63.6	65.5	66.4	61.6	61.2	61.9	61.3	66.8	66.0	64.4	61.2	59.3	58.3	55.6	54.2	51.2	48.2
Yamaha 600cc (SM2)	57.1	57.8	56.6	65.5	56.1	54.9	63.5	64.7	71.2	68.7	70.3	63.6	59.5	63.6	60.9	61.2	60.6	58.3	55.2	52.1	49.9	48.2	44.8	41.5
Polaris 800cc (SM2)	52.5	51.3	57.0	59.5	59.0	59.2	63.8	66.7	61.3	64.7	65.4	60.8	59.2	59.9	61.9	65.4	64.0	60.1	59.3	59.7	59.0	56.1	50.9	49.7
Alpen (Bomb.)	59.7	65.4	66.3	67.0	57.6	61.3	65.2	60.6	60.6	57.6	57.6	57.5	58.4	58.3	57.4	57.7	55.8	56.4	53.6	51.6	50.7	48.2	44.7	41.6
Yellow (Bomb.)	62.3	66.8	64.2	75.5	66.5	66.1	63.8	64.3	65.8	59.6	62.0	63.0	64.2	61.6	61.9	60.1	58.6	56.7	56.9	57.3	58.8	57.9	54.2	46.6
Mattracks Diesel	58.9	61.5	58.1	59.5	70.5	68.8	62.9	77.3	72.4	68.7	64.6	63.5	64.2	65.8	64.4	65.3	63.4	62.2	58.6	55.1	53.6	51.6	50.4	48.7
Mattracks Gas	54.9	65.0	58.5	67.1	68.0	57.9	68.8	70.2	69.0	65.7	63.0	61.7	64.1	64.1	61.6	59.4	57.4	55.9	53.6	50.9	49.2	46.4	43.0	40.5
Fulltrack	54.2	57.8	59.3	58.9	54.6	58.0	62.5	58.5	57.8	57.7	54.8	56.2	56.7	56.7	58.1	59.8	55.3	52.3	50.1	46.9	43.5	40.8	38.6	35.8
Fulltrack BAT (2001)	56.2	55.6	54.8	58.2	66.1	61.5	60.2	62.7	61.0	61.3	59.8	59.6	59.9	60.1	61.6	59.8	59.9	56.8	53.1	49.7	46.5	44.5	42.3	38.3

Table 17: One-third octave-band levels used for developing Noise-Speed-Distance relationships

Type	Class	Spd, mph	Total Band	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
SM	4	30	77.6	47.3	51.2	72.5	54.8	63.6	68.2	64.4	66.8	59.8	69.8	67.3	61.0	57.7	58.9	56.9	58.3	60.4	57.6	56.9	56.3	52.6	49.8	45.4	41.9
SM	4	40	76.6	53.7	53.1	57.4	56.2	67.0	66.6	58.8	65.9	69.9	64.0	65.4	67.4	60.5	58.4	61.4	61.0	61.5	61.5	59.2	55.7	53.6	52.4	49.6	46.1
SM	2	10	72.5	55.9	55.7	60.6	54.6	59.9	68.9	60.5	52.0	55.6	52.5	55.6	58.7	62.2	57.5	58.5	54.3	52.9	51.8	50.6	49.3	46.5	42.1	38.3	35.0
SM	2	20	74.6	43.7	48.8	57.4	58.1	61.0	66.4	66.5	59.4	60.0	62.0	59.9	60.5	64.3	65.0	64.7	59.2	58.8	56.9	56.2	55.1	52.4	48.7	45.4	41.3
SM	2	35	75.3	44.4	49.2	49.2	57.9	57.0	62.6	66.1	63.8	61.3	65.0	64.2	61.2	63.4	65.1	67.2	61.8	61.1	58.9	57.7	56.4	55.7	51.4	47.6	43.7
SM	2	40	78.3	55.1	55.2	54.7	58.7	63.1	59.0	59.5	65.1	75.2	66.2	66.4	66.7	62.6	64.0	63.2	62.5	62.5	61.2	58.8	56.8	53.6	51.9	49.0	45.7
SC	B	15	74.9	63.8	63.5	70.1	62.5	61.7	66.2	65.5	61.3	59.0	55.7	57.9	53.3	57.2	55.5	52.3	51.0	49.8	49.2	46.9	45.1	43.5	43.2	41.2	37.0
SC	B	20	78.2	64.5	64.7	70.3	66.6	67.2	67.6	68.7	69.2	66.6	65.3	63.9	62.0	61.7	59.8	62.0	57.1	56.2	56.7	53.7	52.8	53.0	53.3	48.5	44.8
SC	B	35	82.4	66.6	67.2	69.5	60.7	66.1	78.6	69.2	68.8	70.5	71.8	65.7	66.2	68.8	66.6	65.3	65.1	65.5	62.7	61.8	59.8	56.3	54.1	50.8	47.3
SC	M	10	67.4	55.4	62.5	51.5	52.0	53.6	49.7	55.2	53.4	56.0	57.2	52.4	53.4	51.6	50.7	50.7	50.6	47.5	46.2	44.4	45.7	45.7	46.2	47.3	48.0
SC	M	20	71.4	57.1	51.3	54.2	58.7	53.5	50.8	61.2	59.1	63.3	64.5	60.6	58.7	57.4	59.1	57.0	55.3	52.2	49.4	48.8	48.4	47.7	45.6	42.7	40.8
SC	M	35	75.9	55.9	62.0	55.5	54.8	62.5	61.8	61.6	66.2	70.9	65.0	66.2	62.3	61.9	61.0	61.5	57.9	56.0	54.5	53.8	52.7	52.0	50.7	48.0	45.0
SC	F	10	70.0	63.9	60.2	50.3	62.5	51.0	48.9	51.0	53.1	56.9	50.8	50.0	50.0	51.3	63.8	55.9	48.3	49.2	48.4	46.1	45.3	42.3	40.5	39.0	35.9
SC	F	15	70.7	62.6	56.7	62.4	57.1	63.9	56.9	54.1	55.8	60.7	54.1	54.9	52.8	53.4	54.5	51.8	51.1	47.7	52.8	50.5	48.6	56.7	43.2	40.9	40.4
SC	F	20	73.8	56.5	66.6	55.2	64.2	67.2	52.9	58.9	53.8	58.9	56.5	59.3	59.3	61.8	59.9	61.2	58.6	55.3	55.5	54.8	54.8	58.3	46.8	43.1	42.2
SC	F	35	78.8	56.6	69.2	59.4	74.1	64.9	67.8	62.3	61.9	68.6	66.0	63.2	61.5	63.2	65.7	65.0	62.4	57.4	59.0	56.6	55.3	53.8	49.0	45.1	41.6

Figure 38: Yamaha mountain max snowmobile with two-stroke engine, Reference 9

Figure 39: Red Alpen Guide Bombardier snowcoach with low exhaust, Reference 9

Figure 40: Conversion van snowcoach with Mattracks, Reference 9

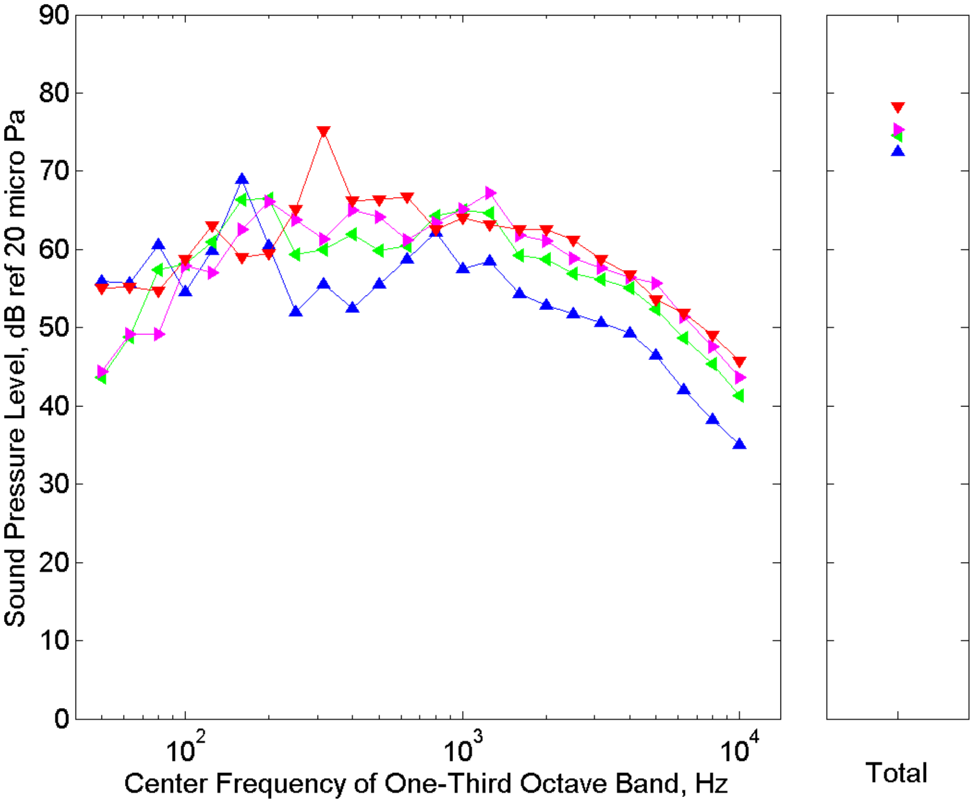

Figure 41: Two-stroke spectra used for generating Noise-Speed-Distance (NSD) relationships. ▼ – Vehicle speed is 40 miles per hour. ▶ – Vehicle speed is 35 miles per hour. ◀ – Vehicle speed is 20 miles per hour. ▲ – Vehicle speed is 10 miles per hour

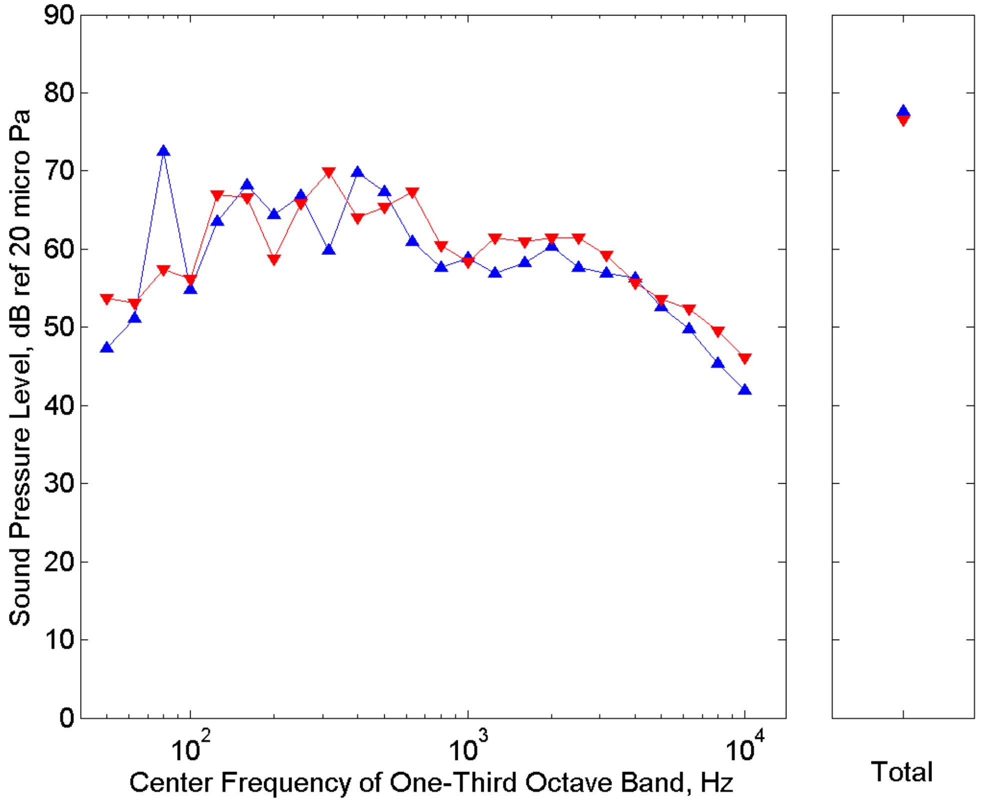

Figure 42: Four-stroke spectra used for generating Noise-Speed-Distance (NSD) relationships. ▼ – Vehicle speed is 40 miles per hour. ▲ – Vehicle speed is 30 miles per hour

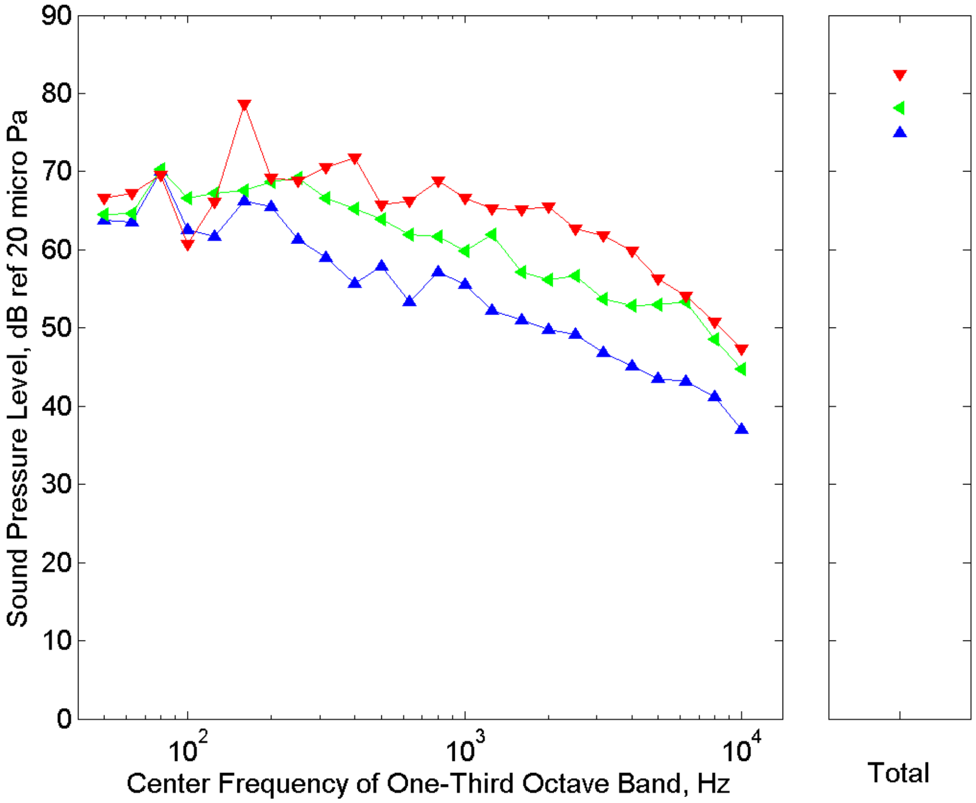

Figure 43: Bombardier spectra used for generating Noise-Speed-Distance (NSD) relationships[a]. ▼ – Vehicle speed is 35 miles per hour. ◀ – Vehicle speed is 20 miles per hour. ▲ – Vehicle speed is 15 miles per hour

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[a] Speed related sound spectra for the Bombardier were limited to the Xanterra (Yellow) Bombardier since this was the only one with sufficient data at different speeds.

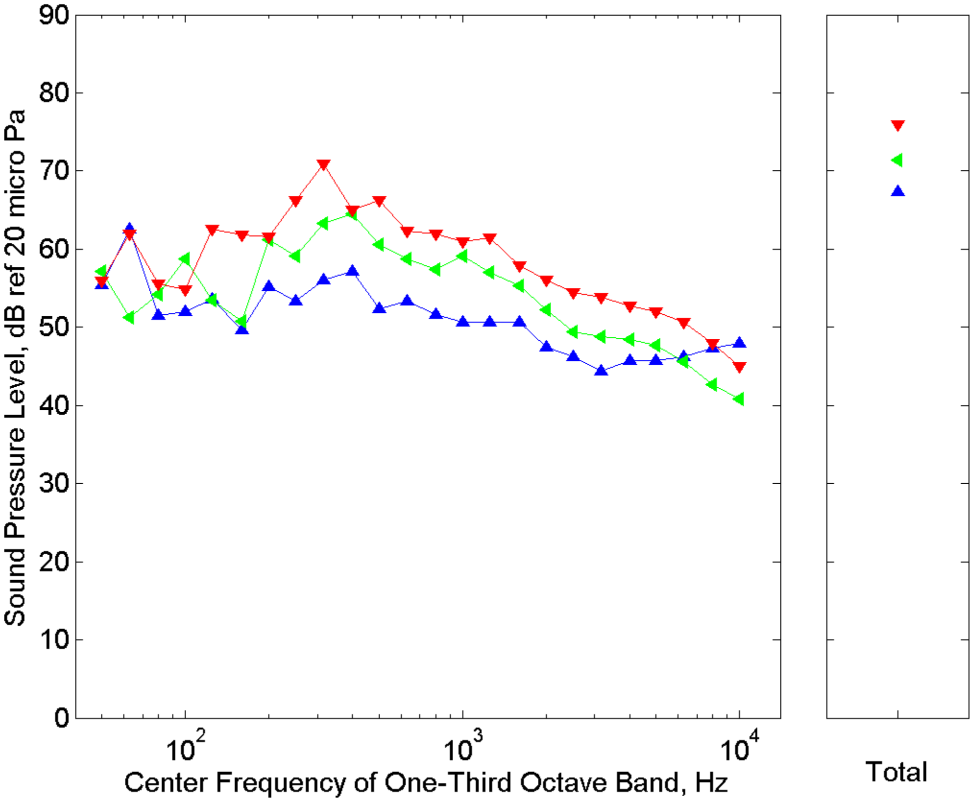

Figure 44: Mattrack spectra used for generating Noise-Speed-Distance (NSD) relationships. ▼ – Vehicle speed is 35 miles per hour. ◀ – Vehicle speed is 20 miles per hour. ▲ – Vehicle speed is 10 miles per hour

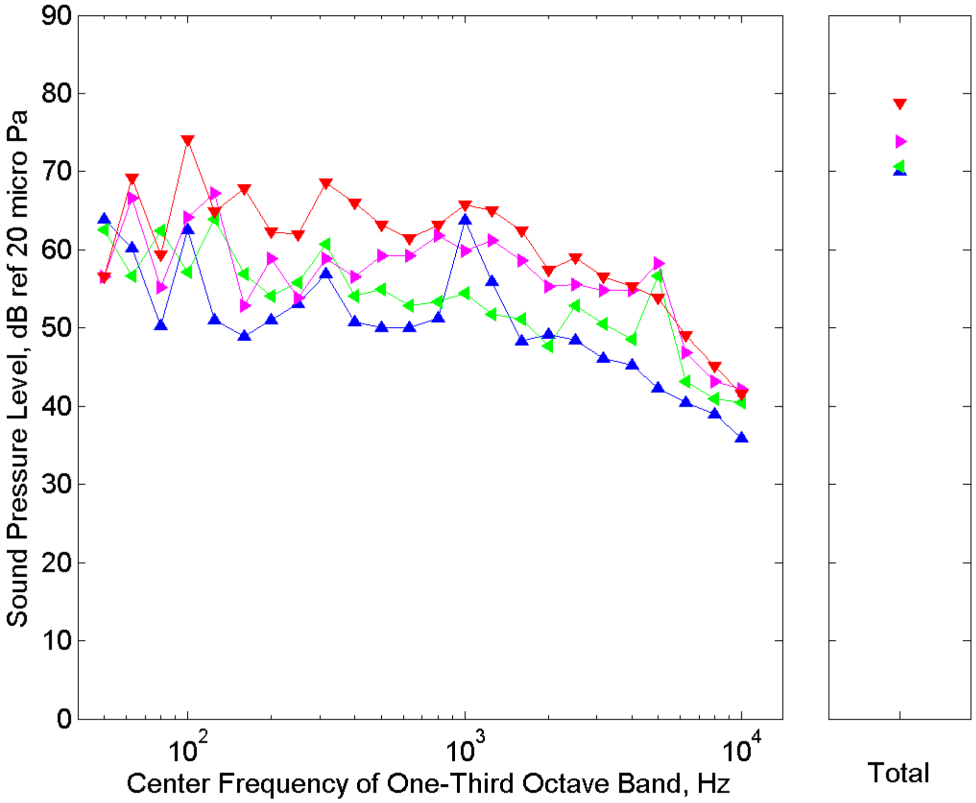

Figure 45: Full-track / Snow Buster spectra used for generating Noise-Speed-Distance (NSD) relationships. ▼ – Vehicle speed is 35 miles per hour. ▶ – Vehicle speed is 20 miles per hour. ◀ – Vehicle speed is 15 miles per hour. ▲ – Vehicle speed is 10 miles per hour

C.2. Grouping of Sound Sources

In previous modeling, see for example results in Appendix D, OSV operations were considered to be evenly distributed throughout the day. The National Park Service was concerned that this may not sufficiently represent the snowmobile operations in the Parks. In order to include snowmobile grouping in the modeling, groups were assumed to be a single point source. It was further assumed that the level of this source increases as a function of the number of snowmobiles in the group,

$$L_{Amax,\,group} = L_{Amax,\,single} + 10 \times \log_{10}(N),$$

where $L_{Amax,\,group}$ is the maximum A-weighted sound level for the group; $L_{Amax,\,single}$ is the maximum A-weighted sound level for a single vehicle of the specified type; and N is the number of vehicles in the group. The term $10 \times \log_{10}(N)$ is used to convert the NSD relationship from single operations to group operations.

When evaluating audibility in the Parks, a point source assumption for groups is suitable for the following reasons. One, validity of the assumption increases with increasing distance. When the distance between the group and the receiver is large, the group will be perceived as a point source. When the distance between the group and the receiver is small, the group will be audible regardless of whether or not they are perceived as a point source. Two, modeling groups as point sources represents a limiting case of the acoustics involved in modeling groups. That is, by modeling the groups as single point sources, the time interval for audibility is at a minimum but the area of effect is at a maximum.

Several sample audibility calculations were run to illustrate the differences between snowmobiles traveling individually and as groups. For this illustration two sample cases were considered, “I”, were snowmobiles were operated individually, and “G” were the snowmobiles were operated in groups. Four-stroke snowmobiles were modeled throughout Yellowstone for a one-hour time interval. Each road segment had either 15, 30, 60, 120, or 240 snowmobiles over the one-hour time interval[a]. The number of operations was determined by the hourly number of snowmobiles and whether they were grouped or not. Thus for example, with 60 snowmobiles per segment for a one-hour time interval, case “I” would have 60 operations (on each road segment), while case “G” would have 6 operations (on each road segment). The combination of sample case and snowmobiles per hour can be thought of as an analog to a modeling scenario. Each grouped operation would have a maximum A-weighted sound level 10 dB[b] greater than the individual operations. The audibility contours are shown in Figure 46 to Figure 55.

By comparing Figure 46 and Figure 47 it can be seen that, for the same number of snowmobiles, individual operations produce higher percent time audible results but “any audibility” is confined to a smaller park area. When the number of snowmobiles is increased to 30, the area nearest the travel corridor reaches 100% audibility for the case “I”, individual operations, but for case “G”, grouped operations, it reaches only about 20% audibility. See Figure 48 and Figure 49. In Figure 50, Figure 52, and Figure 54, the number of snowmobiles is increased from 60 to 240 snowmobiles per hour for individual operations. Over this range, the percent time audible does not increase significantly for individually operated snowmobiles since the maximum audibility has been reached. However, it should be verified that closely spaced snowmobiles can still be treated as point sources. If this is not the case, then the park area with “any audibility” may increase[c]. In Figure 51, Figure 53, and Figure 55, the number of snowmobiles is increased from 60 to 240 snowmobiles per hour for grouped operations. Over this range, the percent time audible increases for group-operated snowmobiles since grouped operations do not reach 100% audibility until about 240 snowmobiles. One final observation, although case “G” with 120 snowmobiles has fewer operations than case “I” with 15 snowmobiles, case “G” has a much greater park area with 100% audibility[d]. This is because the increased sound source levels cause groups to be audible over greater distances along the road. This shows the affect of source level on audibility near the travel corridor.

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[a] For all cases, the line-of-sight blockage was turned off to increase the speed of computation. For the purpose of comparing grouped and non-grouped operations, this is acceptable, however, these results cannot be compared with other results in this report where the line-of-sight blockage was included in the computations.

[b] $10 \times \log_{10}(10)$

[c] The extreme case of this would be when snowmobiles were arranged end-to-end along the length of the road segment, which would form a line source.

[d] It should be remembered that case “I” only has 15 snowmobiles whereas case “G” has 120 snowmobiles.

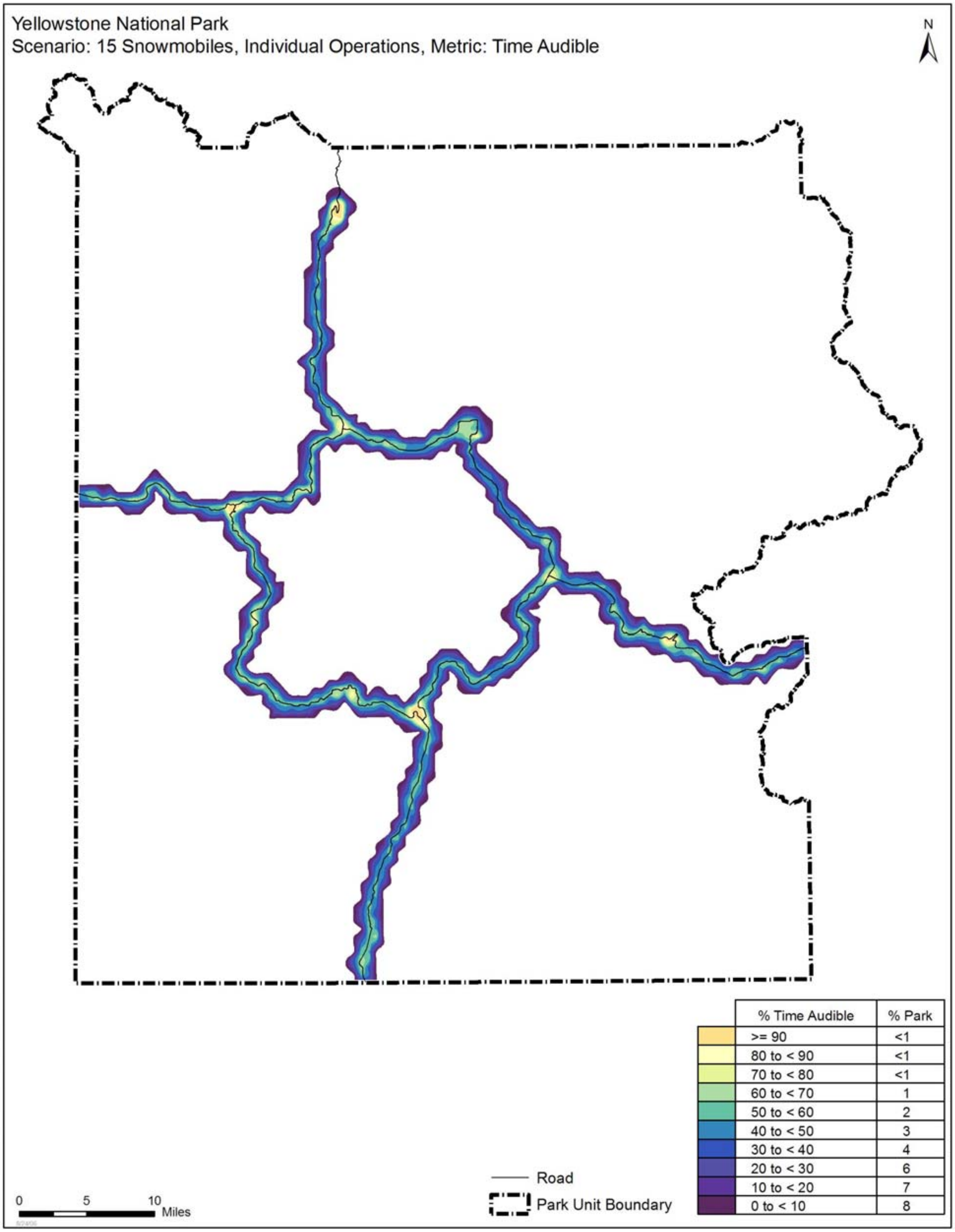


Figure 46: Group study case "I", 15 snowmobiles operated individually on each road segment over a one-hour period.

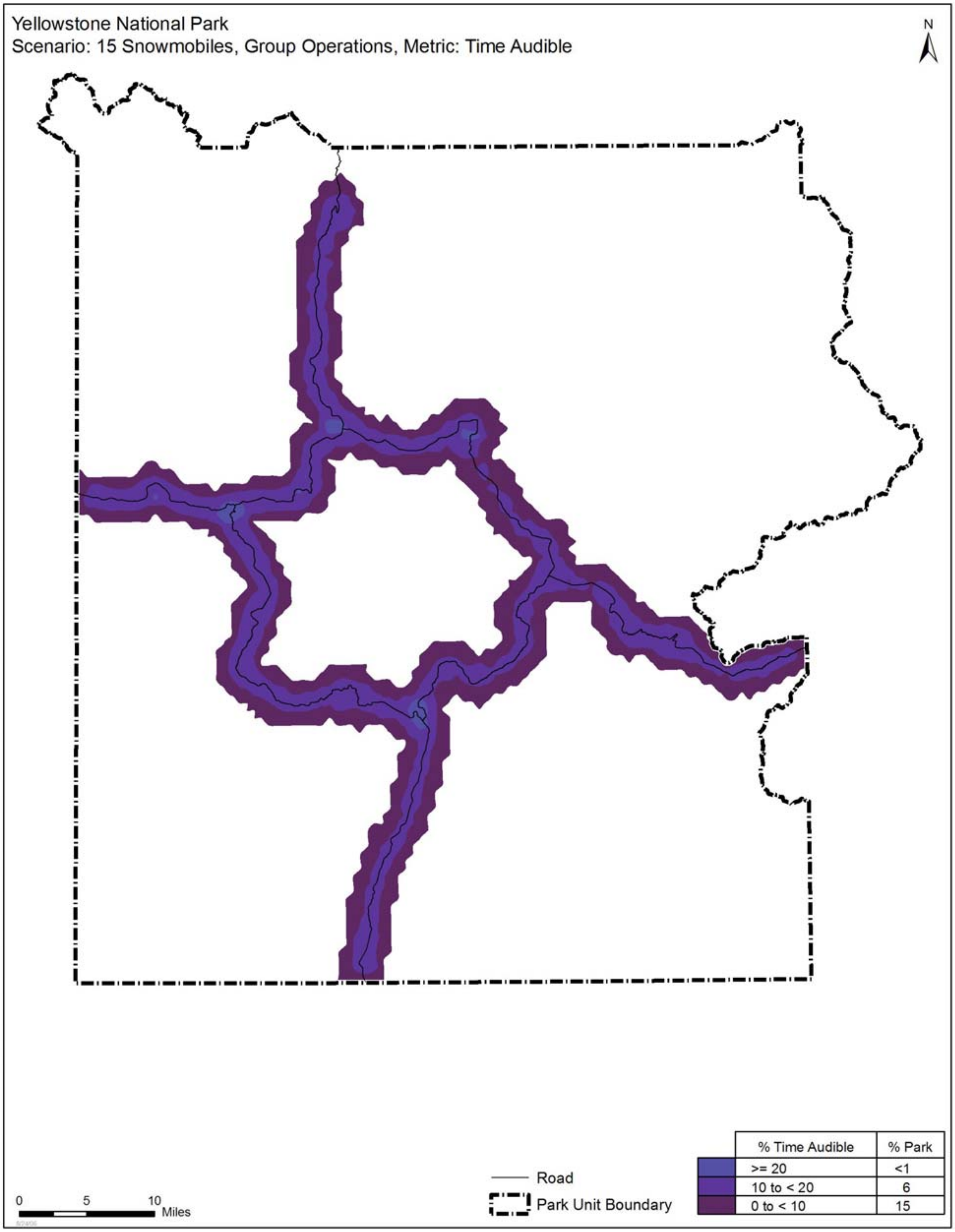


Figure 47: Group study case "G", 15 snowmobiles operated in groups of 10 on each road segment over a one-hour period.

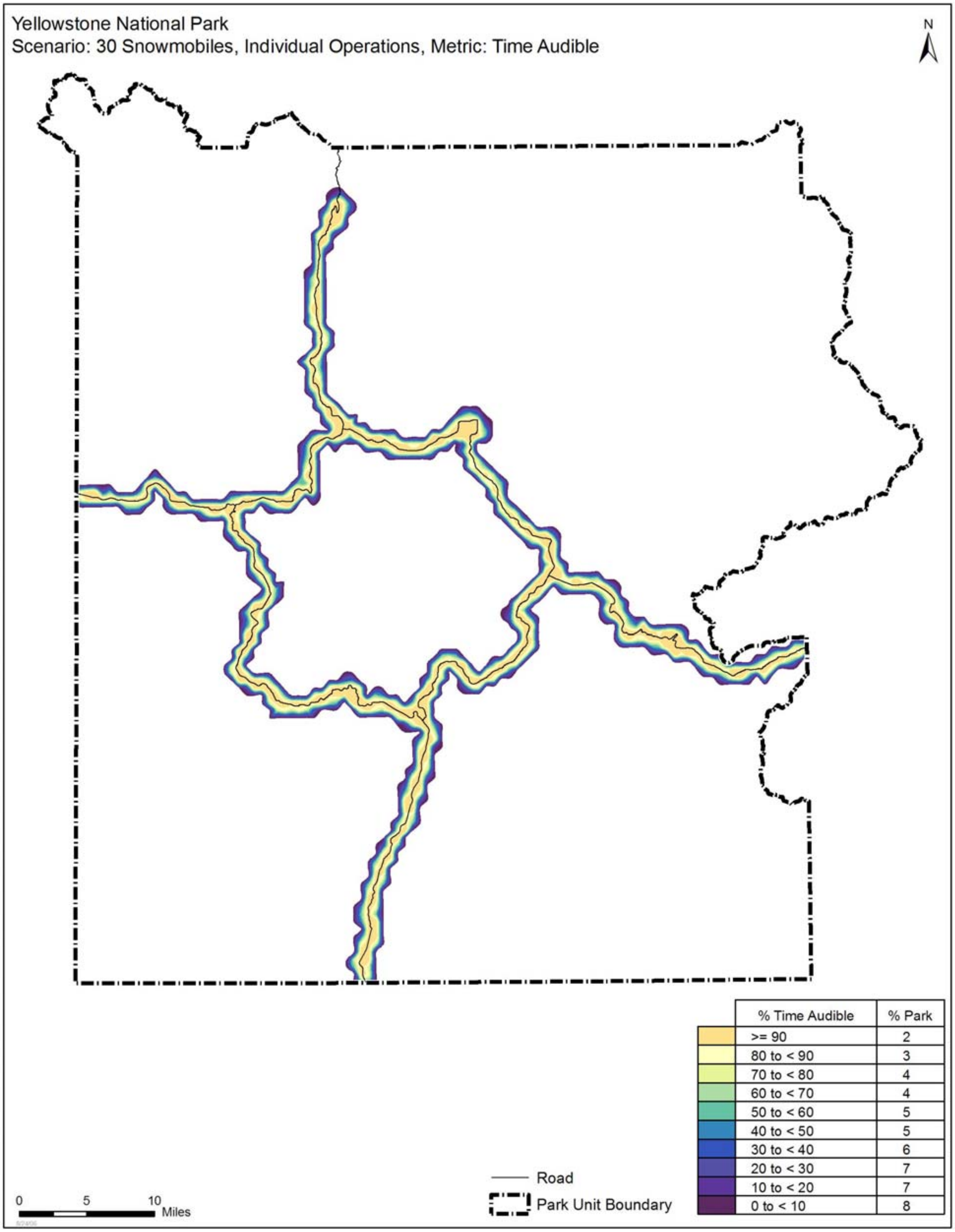
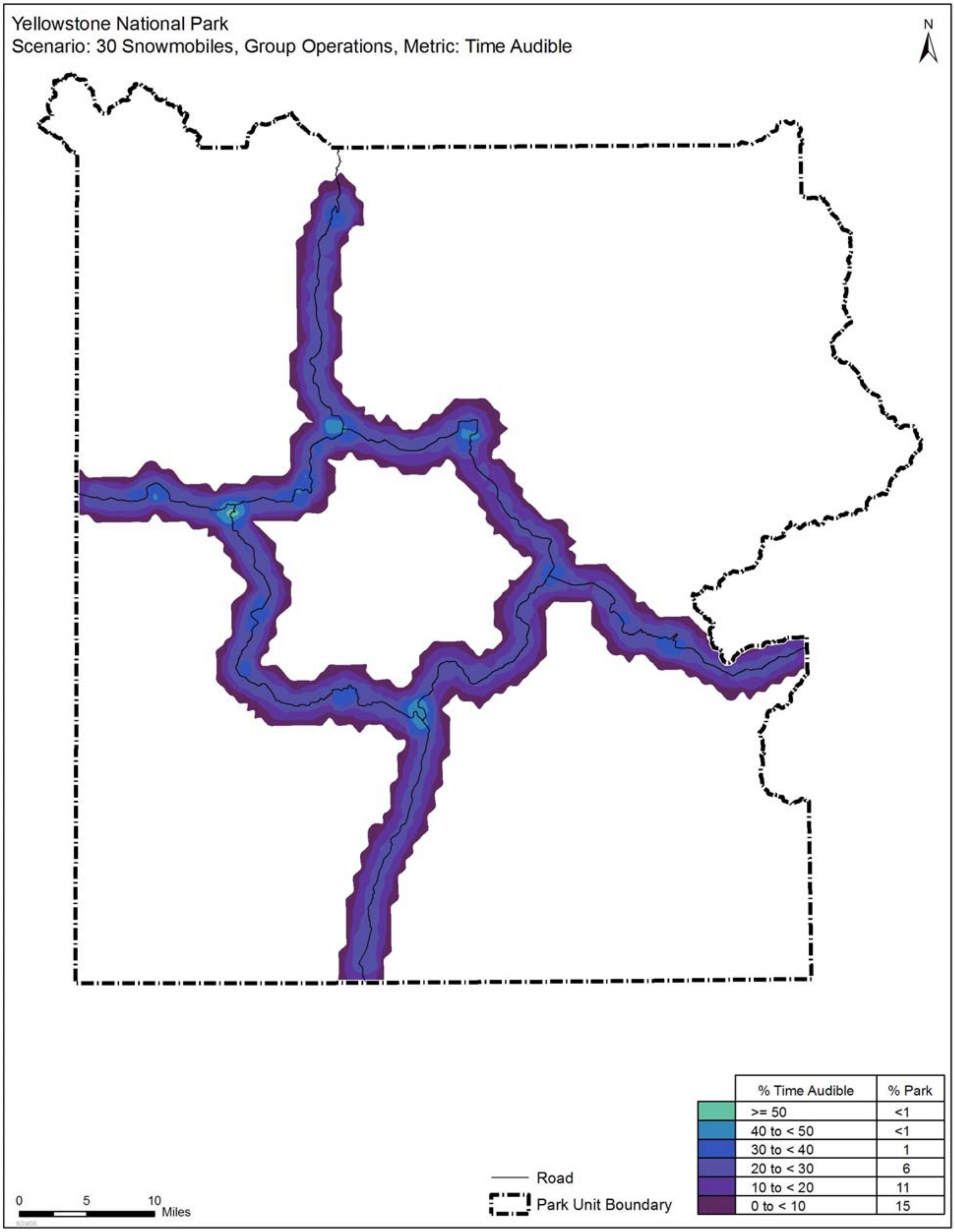


Figure 48: Group study case "I", 30 snowmobiles operated individually on each road segment over a one-hour period.



	% Time Audible	% Park
🟩	>= 50	<1
🟦	40 to < 50	<1
🟦	30 to < 40	1
🟪	20 to < 30	6
🟪	10 to < 20	11
🟪	0 to < 10	15

Figure 49: Group study case "G", 30 snowmobiles operated in groups of 10 on each road segment over a one-hour period.

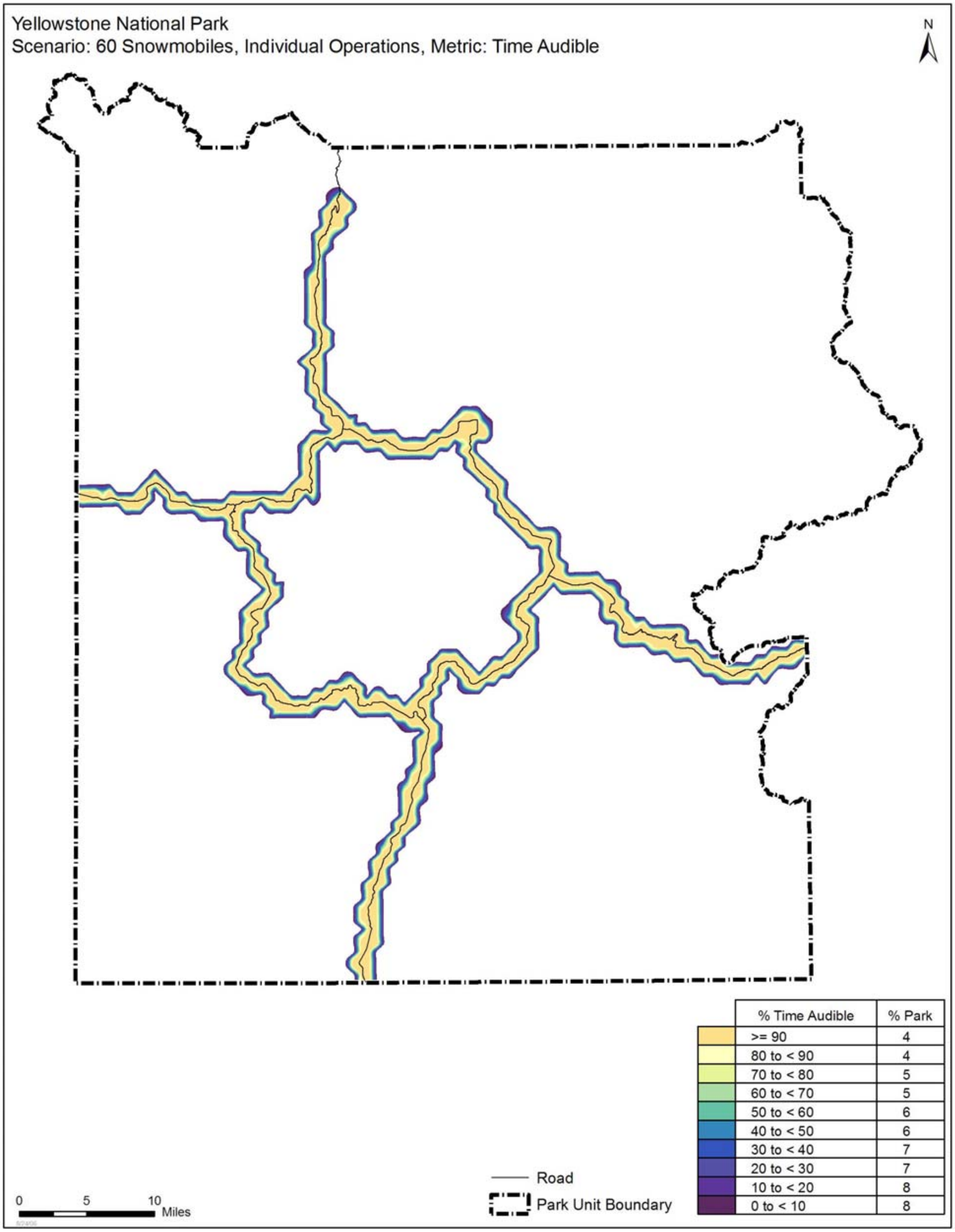


Figure 50: Group study case "I", 60 snowmobiles operated individually on each road segment over a one-hour period.

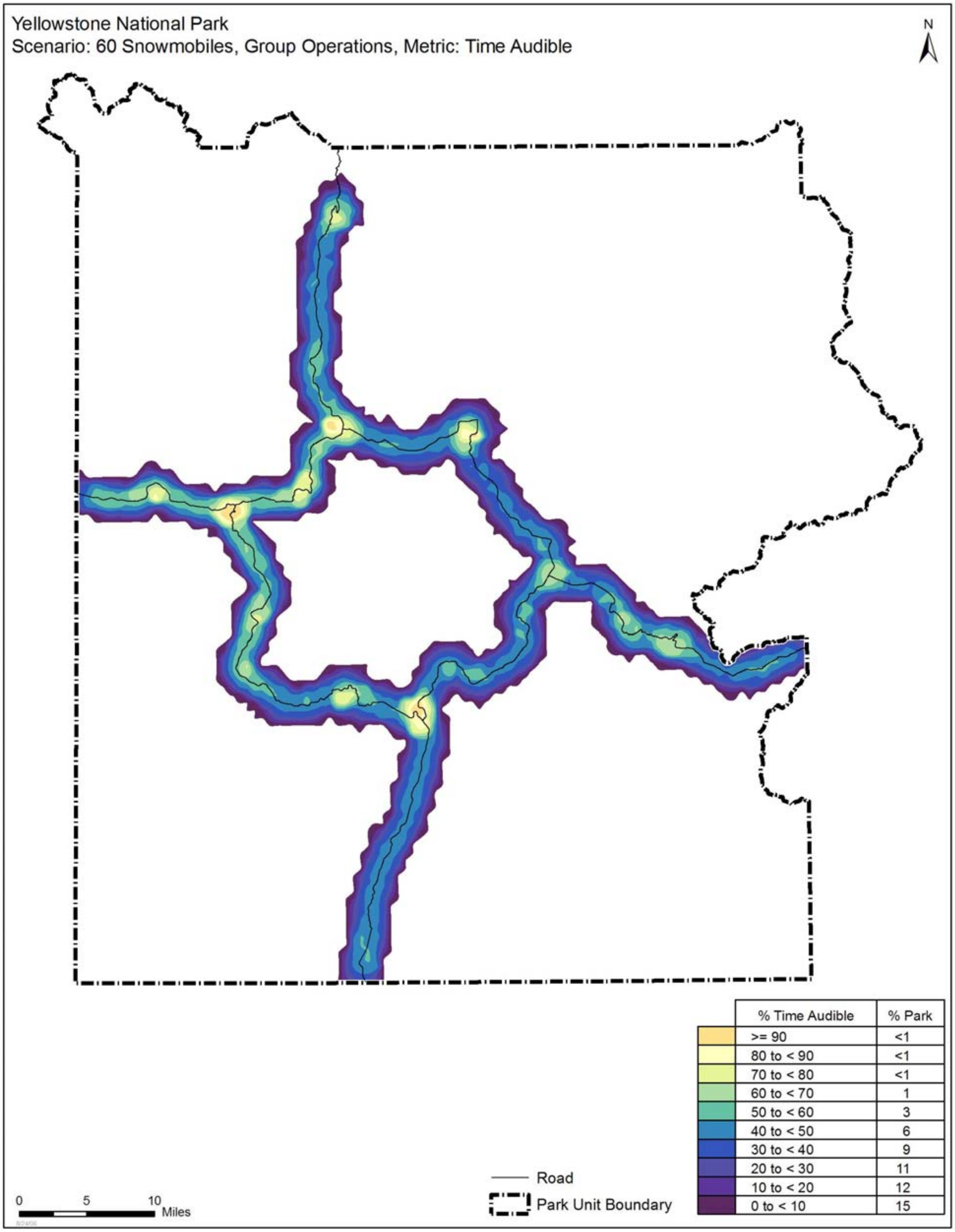


Figure 51: Group study case "G", 60 snowmobiles operated in groups of 10 on each road segment over a one-hour period.

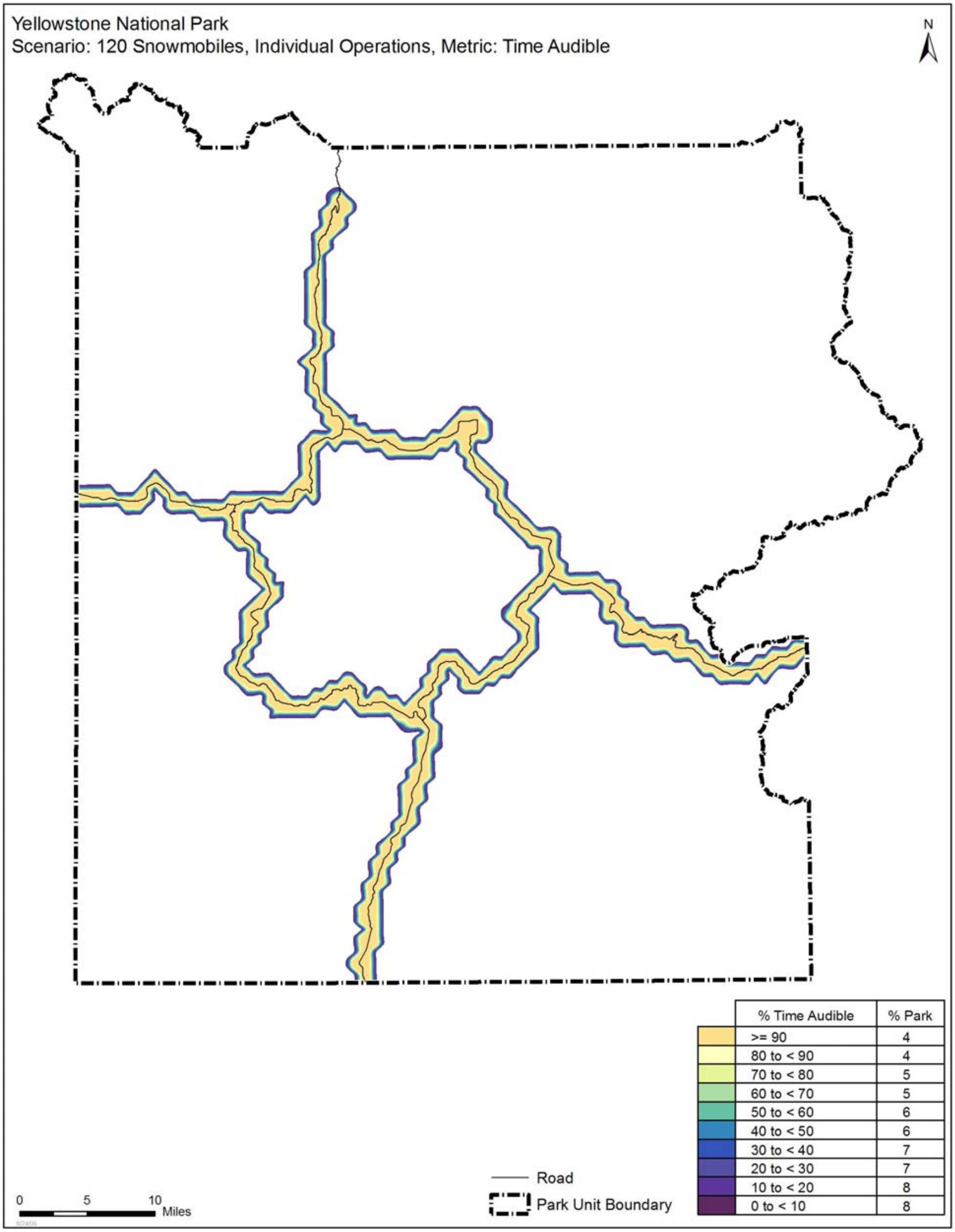
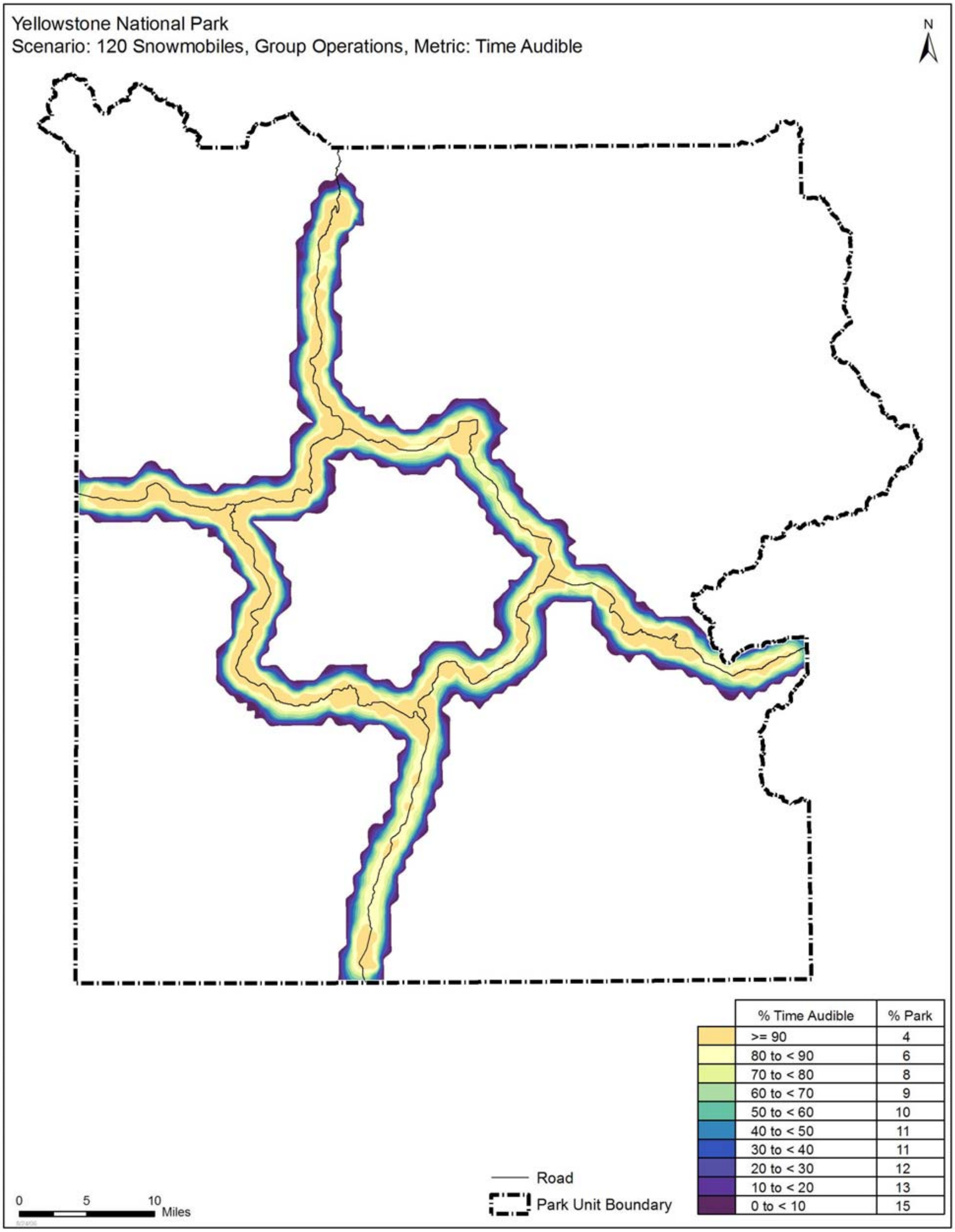


Figure 52: Group study case "I", 120 snowmobiles operated individually on each road segment over a one-hour period.



	% Time Audible	% Park
▨	>= 90	4
▨	80 to < 90	6
▨	70 to < 80	8
▨	60 to < 70	9
▨	50 to < 60	10
▨	40 to < 50	11
▨	30 to < 40	11
▨	20 to < 30	12
▨	10 to < 20	13
▨	0 to < 10	15

Figure 53: Group study case "G", 120 snowmobiles operated in groups of 10 on each road segment over a one-hour period.

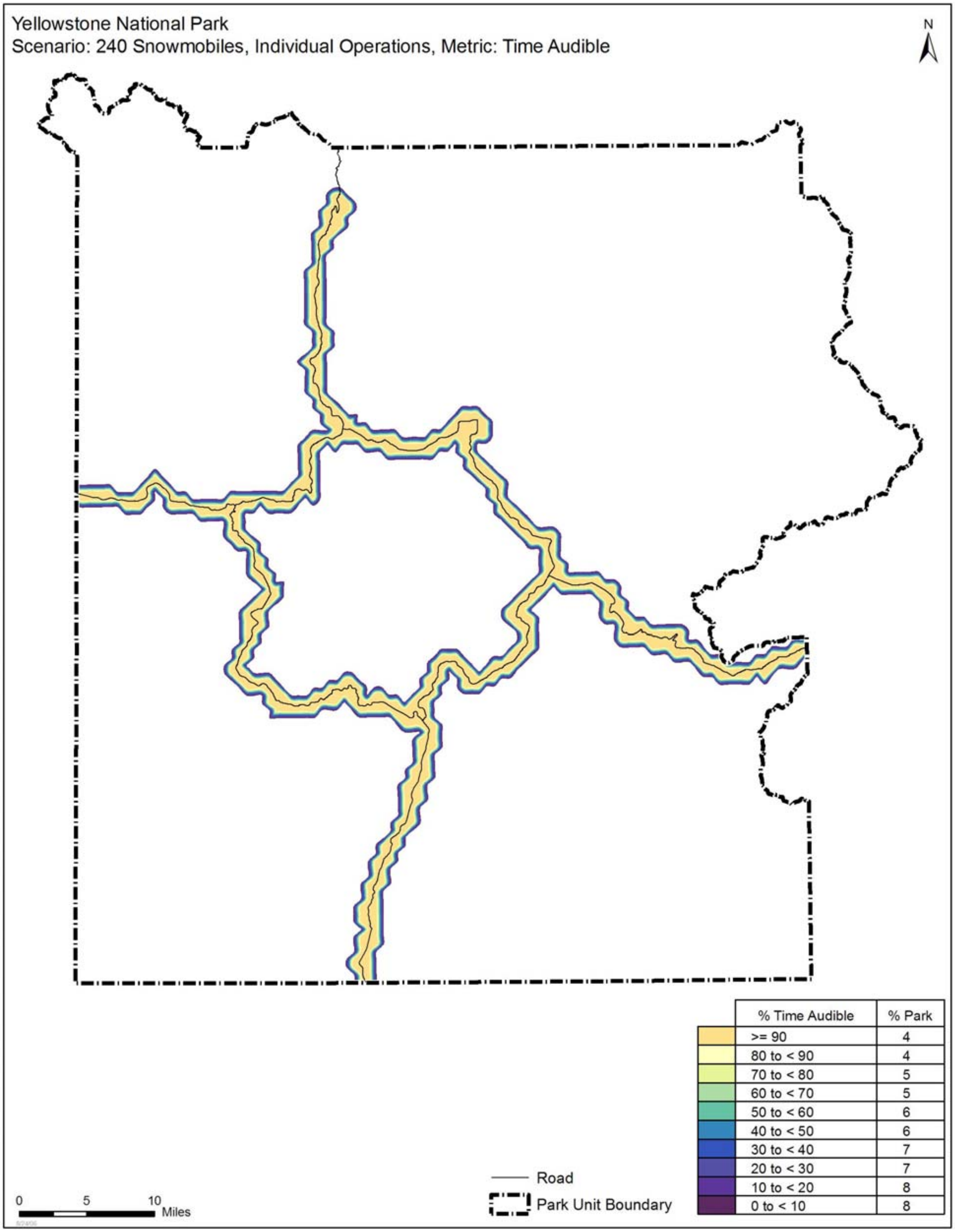


Figure 54: Group study case "I", 240 snowmobiles operated individually on each road segment over a one-hour period.

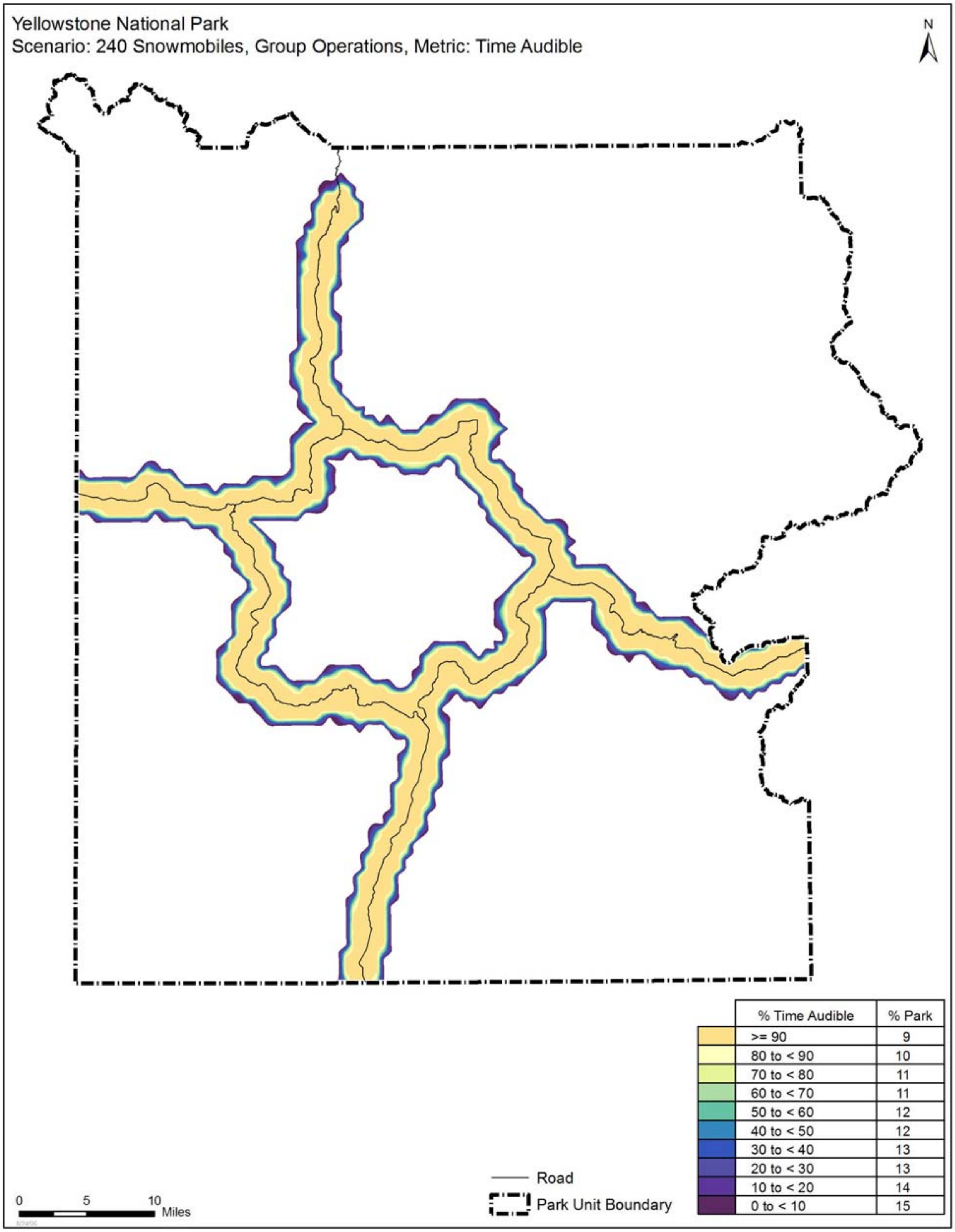


Figure 55: Group study case "G", 240 snowmobiles operated in groups of 10 on each road segment over a one-hour period.