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MODELING SOUND DUE TO OVER-SNOW VEHICLES IN YELLOWSTONE AND GRAND TETON NATIONAL PARKS

October 2006
Final Report

U.S. Department of the Interior
National Park Service

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13. ABSTRACT (Maximum 200 words)

A modified version of the FAA's Integrated Noise Model (INM) Version 6.2 was used to model the sound of over-snow vehicles (OSVs) (snowmobiles and snowcoaches) in Yellowstone and Grand Teton National Parks for ten modeling scenarios provided by the National Park Service (NPS). Version 6.2 was modified to incorporate ground-to-ground sound propagation models consistent with propagation over snow-covered terrain (40 cgs rayls) for OSVs. Sound level relationships were developed for OSVs relating maximum A-weighted sound level (L_{Amax}) to vehicle speed and distance from observer. Audibility and L_{Amax} contours were generated and rank ordered for the ten modeling scenarios according to percent of park covered by a particular contour. In general, the use of Best Available Technology (BAT) OSVs, the reduction in the number of active paths, and the reduction in number of operations all reduced audibility in the parks. These results are expected to help the NPS in refining their winter use plans for the Parks.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

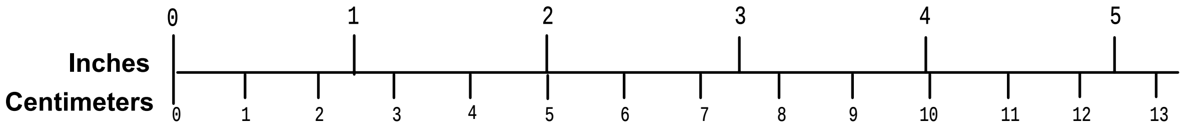
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

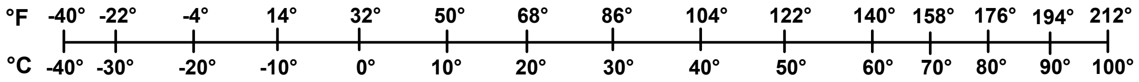
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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EXECUTIVE SUMMARY

The National Park Service (NPS) is developing Winter Use Plans for Yellowstone and Grand Teton National Parks to help manage the use of Over-Snow Vehicles (OSV) in the parks. The use of snowmobiles in the parks is a concern because of increased use and legal actions by environmental, recreational, and commercial groups. Several modeling alternatives are being considered for the NPS Winter Use Plans. These alternatives affect the number of OSVs that are allowed to operate in the parks and where they are allowed to travel. Some modeling alternatives allow standard OSVs while others require the use of Best Available Technology (BAT) OSVs. Some modeling alternatives represent a reduction or cessation of activity while others consider increased operations. The U.S. Department of Transportation, Research and Innovative Technology Administration, John A. Volpe National Transportation Systems Center (Volpe Center) is supporting the NPS by modeling the acoustical environment in the parks associated with each modeling alternative as well as current and historical conditions.

Acoustical modeling was performed by using the Federal Aviation Administration's (FAA) Integrated Noise Model (INM) Version 6.2, adapted for use with OSVs. Model adaptation included the development of ground-to-ground sound propagation models to better account for propagation over snow-covered terrain. Ambient sound levels were provided by the NPS and a set of acoustic zones were developed in order to generate natural ambient maps for the parks. See Figure 1 and Figure 2. The Volpe Center developed Noise-Speed-Distance (NSD) relationships for OSVs based on previously published OSV acoustical studies and winter 2005-2006 measurements. Vehicle types modeled included two- and four-stroke snowmobiles, purpose built snowcoaches, and snowcoaches based on modified conversion vans with either two or four tracks.

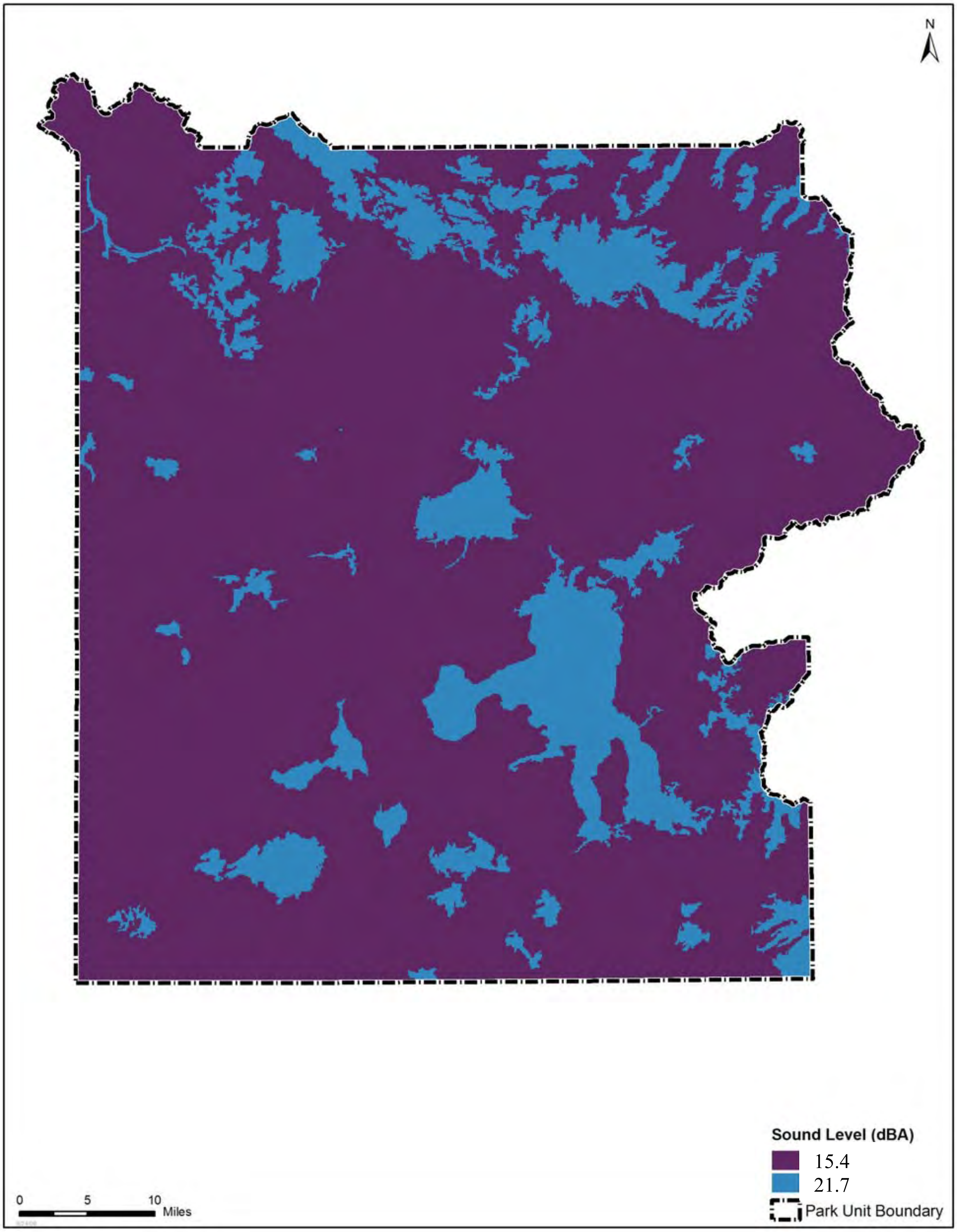

Figure 1: Yellowstone natural ambient map

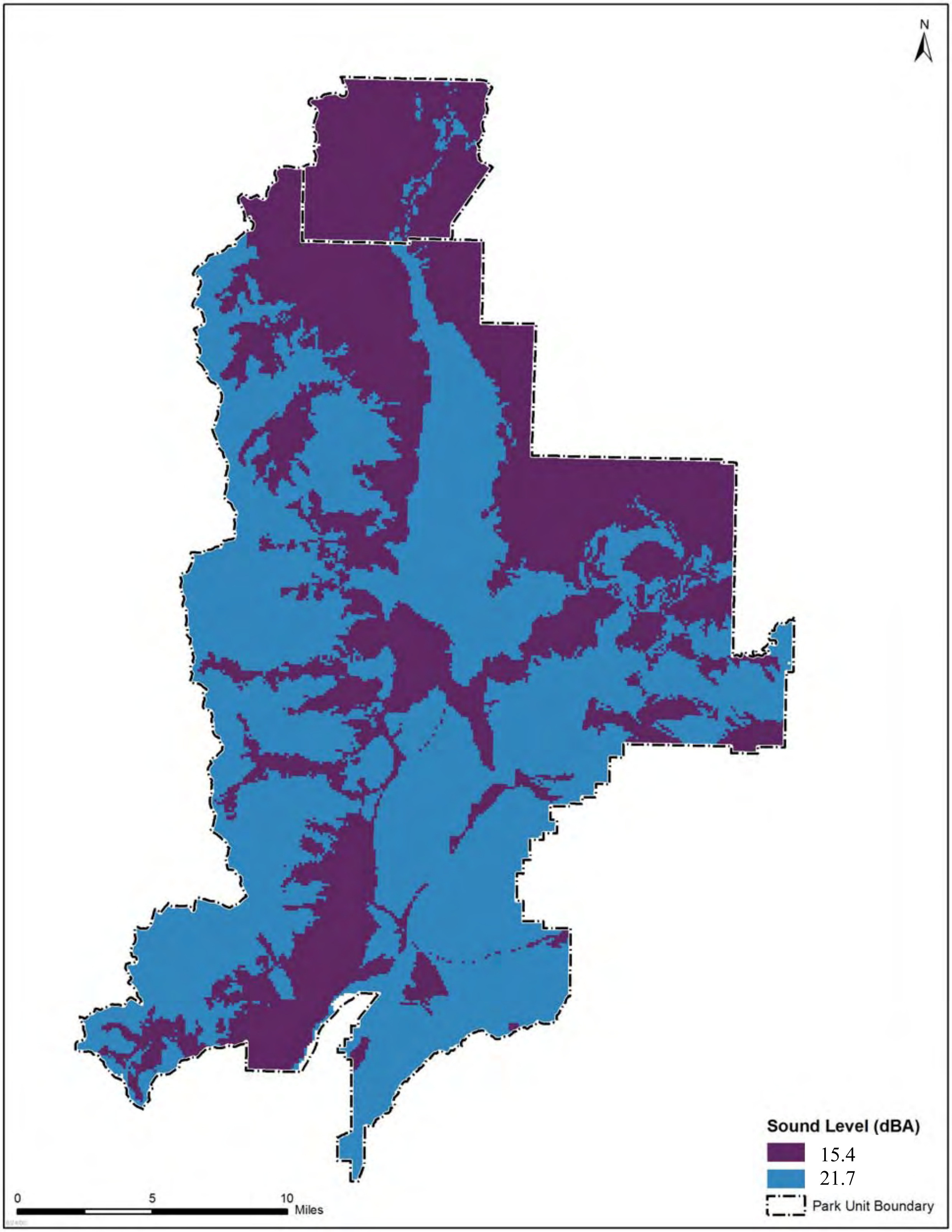

Figure 2: Grand Teton natural ambient map

Each modeling alternative was evaluated for an 8-hour day with temperature, relative humidity, and snow cover representative of an average day during the winter season in the parks. In order to account for increased usage during peak hours, the 8-hour day was divided into 1-hour intervals and vehicle operations were assigned based on scheduling provided by the National Park Service. Modeling alternatives are labeled 1 to 6. Each modeling alternative was designed to model a particular management alternative:

- Modeling Alternative 1 (*Continue Temporary Plan*): This alternative continues the current Temporary Plan into the future with some modifications. This alternative limits the number of snowmobiles and snowcoaches according to NPS specifications found in "Preliminary Draft Alternatives – Winter Use Plans"[1], and requires that all vehicles be guided and of Best Available Technology (BAT). This alternative includes several options as follows:
    - Option A: East entrance to Yellowstone open. (Daily Entrance Limit: 720 snowmobiles / 78 snowcoaches)
    - Option B: East entrance to Yellowstone closed for avalanche control. (Daily Entrance Limit: 720 snowmobiles / 78 snowcoaches)
    - Option C: Was not modeled because the operations were adequately modeled by Option D and E[a].
    - Option D: East entrance to Yellowstone closed and reduced over-snow vehicle use. (Daily Entrance Limit: 680 snowmobiles / 78 snowcoaches)
    - Option E: East entrance to Yellowstone and Gibbon Canyon closed, reduced over-snow vehicle use. (Daily Entrance Limit: 680 snowmobiles / 78 snowcoaches)
- Modeling Alternative 2 (*Snowcoaches Only*): This alternative limits over-snow vehicles to BAT snowcoaches only and would also close the East entrance to Yellowstone. Since snowcoaches do not operate in Grand Teton, no modeling was necessary for Grand Teton. (Daily Entrance Limit: 0 snowmobiles / 120 snowcoaches)
- Modeling Alternative 3 (*Eliminate Most Road Grooming*): This alternative eliminates grooming of most roads in Yellowstone and Grand Teton. The exceptions would be the road segment from the South Entrance to Old Faithful and the Grassy Lake Road. These two roads would continue to be groomed. (Daily Entrance Limit: 250 snowmobiles / 20 snowcoaches)
- Modeling Alternative 4 (*Expand Recreational Use*): This alternative would expand the recreational use of the parks during the winter season. For Yellowstone, BAT requirements would remain in place and about 25% of all snowmobiles would be unguided. For Grand Teton, a portion of the snowmobiles on the road segment from Moran to Flagg Ranch would be allowed to be non-BAT. (Daily Entrance Limit: 1025 snowmobiles / 115 snowcoaches)
- Modeling Alternative 5 (*Provide for Unguided Access*): For Yellowstone, BAT requirements would remain in place and about 20% of all snowmobiles would be unguided. This alternative does not increase the number of over-snow vehicles in operation, in contrast to Modeling Alternative 4. (Daily Entrance Limit: 625 snowmobiles / 100 snowcoaches)

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[a] Based on "Travel Factors by Alternative_with Exit Factors_22May2006.xls" from the NPS

- Modeling Alternative 6 (*Mixed Use*): This alternative allows for the use of both over-snow vehicles as well as wheeled vehicles, namely Busses and Vans. The wheeled vehicles would travel on plowed roads on the west side of Yellowstone, whereas the other road sections would be groomed for over-snow vehicle use. (Daily Entrance Limit: 350 snowmobiles / 40 snowcoaches / 100 wheeled vehicles)
- Current Condition: The Current Condition evaluates the level of *use* during the most recent winter seasons. This includes BAT requirements for snowmobiles but not for snowcoaches. The Current Condition also requires guides for all vehicles in Yellowstone, but not for Grand Teton. (Average Daily Entrance[a]: 260 snowmobiles / 29 snowcoaches)
- Historical Condition: The Historical Condition considers a return to the 1983 Regulations guiding winter use in the parks. This would remove limits to visitor use and eliminate Best Available Technology requirements[b]. (Average Daily Entrance: 1400 snowmobiles / 40 snowcoaches)

Percent time audible (%TAUD) contours and time above A-weighted level in seconds (TALA) were calculated for the modeling alternatives, as well as for current and historical conditions. The percent time audible contours had highest levels near the OSV travel corridors. Increases in operations increased the highest percent time audible up to a maximum of 100%. Increases in group size and the inclusion of snowcoaches that do not meet Best Available Technology (BAT) specifications increased the park area with "any audibility". Although not intuitive, inclusion of snowmobiles that do not meet BAT specifications did not increase the park area with "any audibility". Although these results were initially thought to be erroneous, further investigation indicated them to be correct and to be a result of the spectra associated with BAT and non-BAT snowmobiles. Specifically, the sound levels from non-BAT snowmobiles attenuated faster with increasing distance than the sound levels from BAT snowmobiles, which had greater sound energy at low frequencies. However, non-BAT snowmobile sound levels near the travel corridor were higher than BAT snowmobiles. Similar trends were found from the results of the TALA calculations.

The modeling alternatives, as well as current and historical conditions, were rank ordered based on park area associated with the Integrated Noise Model's calculated percent time audible contours. Yellowstone rankings are shown in Figure 3 and Grand Teton rankings are shown in Figure 4 for the case of any audible events. Figure 5 shows the Yellowstone ranking for the case of audibility 50 percent of the time, i.e., these values represent the percent of park area in which OSVs are audible at least 50 percent of the 8-hour study period. The percent TAUD was generally bellow 20%. Because of these lower percentages, an analysis of 50% time audible was not conducted for Grand Teton.

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[a] For Current and Historical Conditions, the estimated average daily entrance numbers are used instead of a prescribed limit. The estimates were provided by the NPS.

[b] The 1983 regulations describe a type and amount of snowmobile use that was found to constitute impairment of park resources and values in the 2000 EIS and the 2003 SEIS.

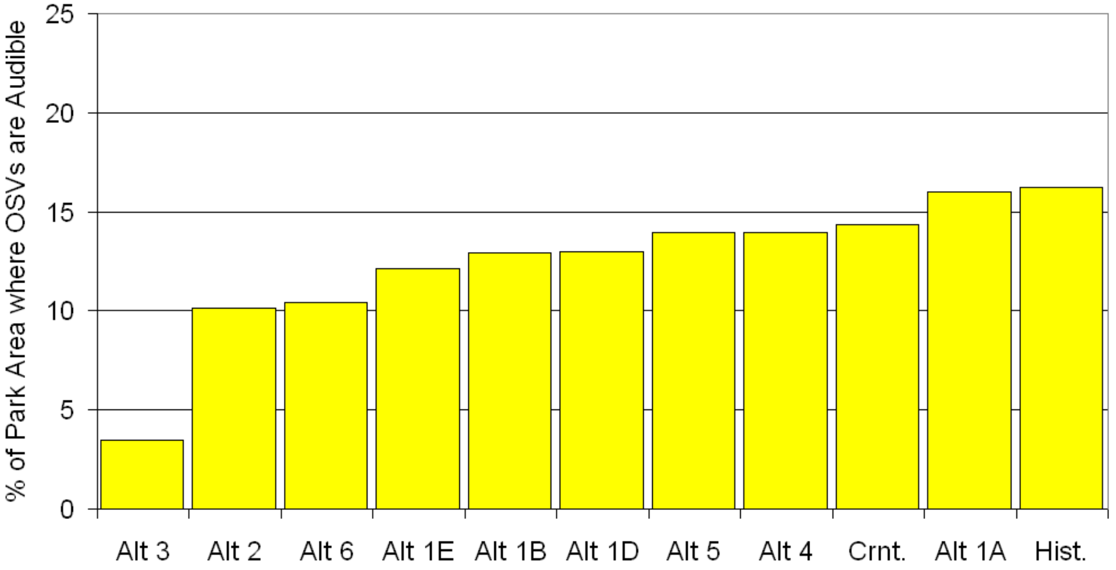

Figure 3: Percent of Yellowstone with any level of OSV audibility

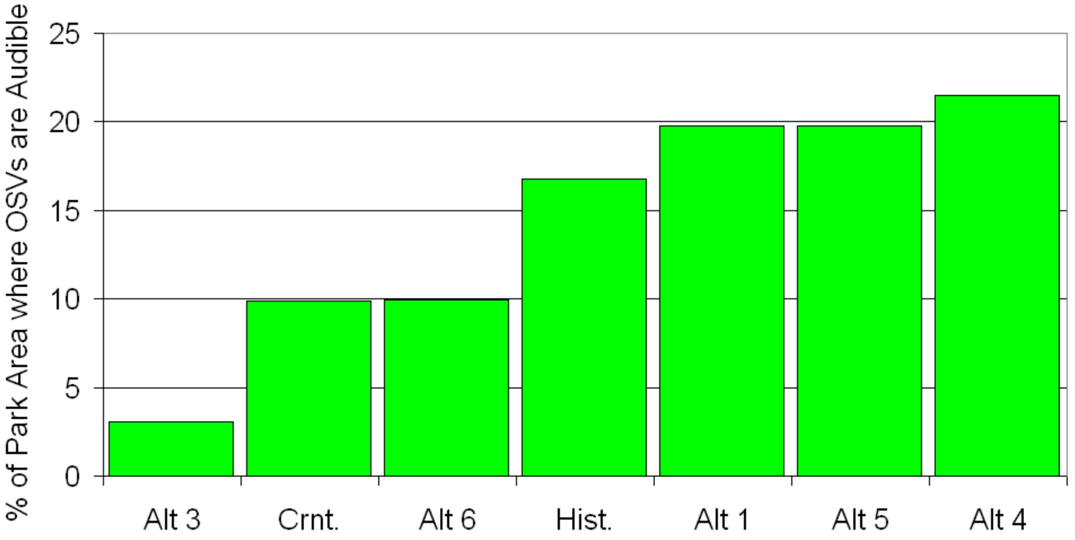

Figure 4: Percent of Grand Teton with any level of OSV audibility

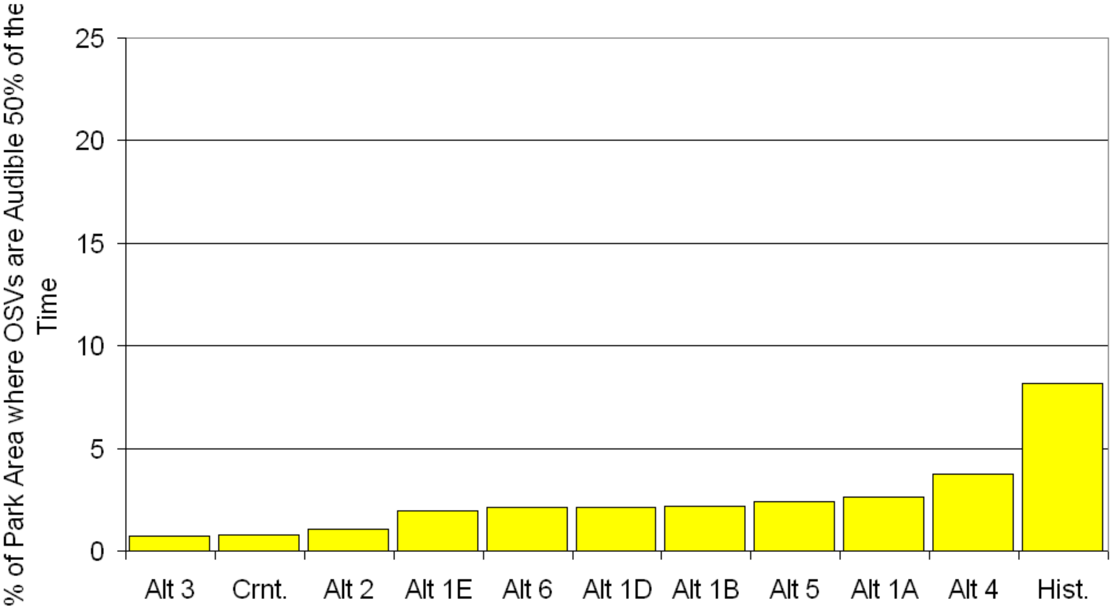

Figure 5: Percent of Yellowstone with 50% OSV audibility

Recommendations for further work include:

- Collect additional source data.
    - Include a greater range of vehicles and speeds to better represent the Park's OSV fleet. This should include any vehicles that make up a significant portion of the operations to be modeled, especially if no vehicles with similar acoustic characteristics have already been included.
    - Include a greater number of repetitions to provide more statistical confidence in the mean levels.
- Run controlled operations for validation, e.g. measure L_{Amax} at several locations simultaneously for a single snowmobile.
- Run modeling alternatives for cold and warm days and humid and dry days to determine sensitivity to weather extremes.
- Run alternatives for different types of snow cover, e.g., freshly fallen snow versus ice. This will require further modeling of ground effects.
- Use park fleet distributions to weight source data for each vehicle model when estimating the mean level for each source type. For example if there are 200 Snowbuster snowcoaches and 100 Bombardier snowcoaches in the park fleet, then the Snowbusters could be counted twice and the Bombardiers could be counted once when averaging source levels.
- Conduct surveys to determine visitor responses to alternatives that can be modeled. Averaged response ratings could be correlated to acoustic metrics such as percent time audible. This would provide an understanding of what metric levels are acceptable to park visitors.

It is understood that these tasks represent a large investment of several groups' time and resources. Further discussion needs to be conducted in order to prioritize these and to determine which items are actionable for an updated version of this study.

TERMINOLOGY

This section presents pertinent terminology used throughout the document. Note: Definitions are generally consistent with those of the American National Standards Institute (ANSI) and References 2 through 6.[2,3,4,5,6]

A-WEIGHTING - A frequency-based methodology used to account for changes in human hearing sensitivity as a function of frequency. The A-weighting network de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 kHz and 6.3 kHz, in an effort to simulate the relative response of human hearing.

ACOUSTIC ENERGY - Commonly referred to as the mean-square sound-pressure ratio, sound energy, or just plain energy, acoustic energy is the squared sound pressure (often frequency weighted), divided by the squared reference sound pressure of 20 µPa, the threshold of human hearing. It is arithmetically equivalent to $10^{LEV/10}$, where LEV is the sound level, expressed in decibels.

AMBIENT - The composite, all-inclusive sound associated with a given environment, excluding the analysis system's electrical noise and sound sources of interest. Several definitions of ambient noise have been adopted by different organizations depending on their application.

- *Existing Ambient*: The composite, all-inclusive sound associated with a given environment, excluding only the analysis system's electrical noise (i.e., snowcoach and snowmobile-related sounds are included);
- *Existing Ambient Without Over-Snow Vehicles* : The composite, all-inclusive sound associated with a given environment, excluding the analysis system's electrical noise and the sound source of interest, in this case, snowcoaches and snowmobiles;
- *Natural Ambient*: The natural sound conditions found in a study area, including all sounds of nature (i.e., wind, streams, wildlife, etc.), and excluding all human and mechanical sounds.

ANNOYANCE - Any bothersome or irritating occurrence.

AUDIBILITY - Refers to the capacity of a human with normal hearing to detect the presence of sound. Additionally, the sound pressure levels and frequency content of ambient sounds influence the ability of a human to hear a given sound.

C-WEIGHTING - A frequency-based methodology that is linear over the mid frequency range from 200 Hz to 1.6 kHz, and de-emphasizes the low (below 200 Hz) and high (above 1.6 kHz) frequencies.

CGS RAYLS – A single parameter, which relates the effect of a ground surface on a sound field. 1 cgs rayl = 1000 Pa sec/m^2.

DAY-NIGHT AVERAGE SOUND LEVEL (DNL, denoted by the symbol L_{dn}) - A 24-hour time-averaged sound exposure level (see definition below), adjusted for average-day sound source operations. In the case of aircraft noise, a single operation is equivalent to a single aircraft operation. The adjustment includes a 10-dB penalty for operations occurring between 2200 and 0700 hours, local time.

DECIBEL - (symbol dB) A unit of measure for defining a noise level or a noise exposure level. The number of decibels is calculated as ten times the base-10 logarithm of the squared sound pressure (often frequency weighted), divided by the squared reference sound pressure of 20 μPa, the threshold of human hearing.

DOSE RESPONSE - Quantitative dose data (e.g. noise data measured in the field), correlated with qualitative response data (e.g. visitors' responses to a questionnaire).

EQUIVALENT AUDITORY SYSTEM NOISE (EASN) – Estimate of the internal noise in human auditory system. The levels used in this report are based on those presented in Reference 14.

EQUIVALENT SOUND LEVEL (TEQ, denoted by the symbol L_{AeqT}) - Ten times the base-10 logarithm of the time-mean-square, instantaneous A-weighted sound pressure, during a stated time interval, T (where $T=t_2-t_1$, in seconds), divided by the squared reference sound pressure of 20 μPa, the threshold of human hearing. L_{AeqT} is related to L_{AE} by the following equation:

$$L_{AeqT} = L_{AE} - 10Lg(t_2-t_1) \qquad \text{(dB)}$$

Where L_{AE} = Sound exposure level (see definition below).
The L_{Aeq} for a specific time interval, T1 (expressed in seconds), can be normalized to a longer time interval, T2, via the following equation:

$$L_{AeqT2} = L_{AeqT1} - 10Lg(T2/T1) \qquad \text{(dB)}$$

FREQUENCY – For a function periodic in time, the reciprocal of the period (the smallest increment of an independent variable for which a function repeats itself).

HARD GROUND - Any highly reflective surface in which the phase of the sound energy is essentially preserved upon reflection; examples include water, asphalt and concrete.

HERTZ - (abbreviation Hz) Unit of frequency, the number of times a phenomenon repeats itself in a unit of time.

L_{50} - A statistical descriptor describing the sound level exceeded 50 percent of a specific time period. For example, from a fifty-sample measurement period with the samples sorted from highest sound level to lowest sound level, the twenty-fifth sound level is the 50-percentile exceeded sound level

L_{90} - A statistical descriptor describing the sound level exceeded 90 percent of a specific time period. For example, from a fifty-sample measurement period with the samples sorted from highest sound level to lowest sound level, the forty-fifth sound level is the 90-percentile exceeded sound level

L_{AE} (see Sound Exposure Level)

L_{Aeq} (see Equivalent Sound Level)

L_{ASmx} (see Maximum Sound Level)

L_{dn} (see Day-Night Average Sound Level)

L_x - A statistical descriptor describing the sound level exceeded "x" percent of a specific time period, e.g., L_{50} and L_{90}.

LINE SOURCE - Multiple point sources moving in one direction, radiating sound cylindrically. Note: Sound levels measured from a line source decrease at a rate of 3 dB per doubling of distance.

LOW-LEVEL NOISE ENVIRONMENT - An outdoor sound environment typical of a remote suburban setting, or a rural or public lands setting. Characteristic day-night average sound levels (DNL, represented by the symbol, L_{dn}) would generally be less than 45 dB, and the everyday sounds of nature, e.g., wind blowing in trees and birds chirping would be a prominent contributor to the DNL.

MAXIMUM SOUND LEVEL - The maximum A-weighted sound level associated with a given event (see figure with definition of sound exposure level). Fast exponential response (L_{AFmx}) and Slow exponential response (L_{ASmx}) characteristics effectively damp a signal as if it were to pass through a low-pass filter with a time constant (τ) of 125 and 1000 milliseconds, respectively.

NATURAL AMBIENT (see Ambient)

NOISE - Any unwanted sound. "Noise" and "sound" are used interchangeably in this document.

NOISE DOSE - A measure of the noise exposure to which a person is subjected.

NOISE-POWER DISTANCE (NPD) DATA – A set of noise levels representing a particular vehicle/engine combination in the Federal Aviation Administration's Integrated Noise Model, expressed as a function of: (1) engine power, usually the corrected net thrust per engine; and (2) source-to-receptor distance.

NOISE-SPEED-DISTANCE (NSD) DATA – A set of noise levels representing a particular vehicle/engine combination in the Federal Aviation Administration's Integrated Noise Model, expressed as a function of: (1) vehicle speed; and (2) source-to-receptor distance. NSDs are a modified form of NPDs used specifically for the purposes of the current study.

OVER-SNOW VEHICLE (OSV) – Any vehicle designed for the purpose of traveling over snow-covered terrain. In this report, OSVs are limited to snowmobiles and snowcoaches.

OVERLOOK - Any front country location in a study area subject to substantial human activity, or destinations reached by automobile or bus, and generally traversable within thirty minutes.

PERCENT TIME-ABOVE – The percentage of time that a time-varying sound level is above a given sound level threshold.

PERCENT TIME-AUDIBLE – The percentage of time that a time-varying sound level can be heard by a receiver in a given area during a given time period.

POINT SOURCE - Source that radiates sound spherically. Note: Sound levels measured from a point source decrease at a rate of 6 dB per doubling of distance in a free field.

SOFT GROUND - Any highly absorptive surface in which the phase of the sound energy is changed upon reflection; examples include terrain covered with dense vegetation or freshly fallen snow. (Note: At grazing angles greater than 20 degrees, which can commonly occur at short ranges, or in the case of elevated sources, soft ground becomes a good reflector and can be considered hard ground).

SOUND – Auditory sensation evoked by the oscillation in pressure, stress, particle displacement, particle velocity, etc., in a medium with internal forces (e.g., elastic or viscous), or the superposition of such propagated oscillations.

SOUND EXPOSURE LEVEL (SEL, denoted by the symbol L_{AE}) –
Over a stated time interval, T (where $T=t_2-t_1$, in seconds), ten times the base-10 logarithm of a given time integral of squared instantaneous A-weighted sound pressure, divided by the product of the squared reference sound pressure of 20 μPa, the threshold of human hearing, and the reference duration of 1 sec. The time interval, T, must be long enough to include a majority of the sound source's acoustic energy. As a minimum, this interval should encompass the 10-dB down points (see Figure 6).

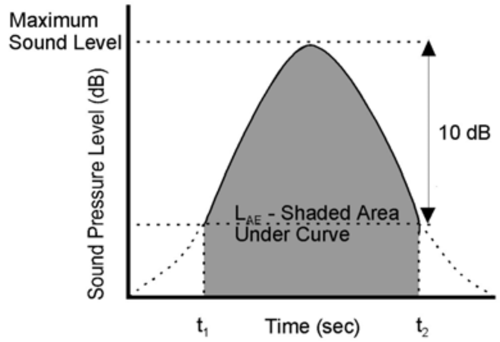

Figure 6: Graphical representation of L_{AE}.

The L_{AE} can be developed from 1-second, A-weighted sound levels (L_{Ak}) by the following equation:

$$L_{AE} = 10Lg\left[\sum_{k=t_1}^{t_s} 10^{L_{AK}/10}\right] \quad \text{(dB)}$$

In addition, L_{AE} is related to L_{AeqT} by the following equation:

$$L_{AE} = L_{AeqT} + 10Lg(t_2 - t_1) \qquad \text{(dB)}$$

Where L_{AeqT} = Equivalent sound level in dB (see definition above).

SOUND PRESSURE LEVEL (SPL) - Ten times the base-10 logarithm of the time-mean-square sound pressure, in a stated frequency band (often frequency-weighted), divided by the squared reference sound pressure of 20 μPa, the threshold of human hearing.

$$SPL = 10Lg[p^2 / p_{ref}^2]$$

Where p^2 = time-mean-square sound pressure; and p_{ref}^2 = squared reference sound pressure of 20 μPa.

SPECTRUM – A set of sound pressure levels in component frequency bands, usually one-third octave-bands.

TIME-ABOVE – The duration that a time-varying sound level is above a given sound level threshold in a given area during a given time period.

TIME-AUDIBLE – The duration of time that a time-varying sound level can be heard by a receiver in a given area during a given time period.

Z-WEIGHTING – Indicates no frequency-based methodology was used (also referred to as flat, no weighting, or unweighted).

1. Introduction

The National Park Service (NPS) is developing Winter Use Plans for Yellowstone and Grand Teton National Parks to help manage the use of Over-Snow Vehicles (OSV) in the parks. The U.S. Department of Transportation, Research and Innovative Technology Administration, John A. Volpe National Transportation Systems Center (Volpe Center) is supporting the NPS by modeling the acoustical environment in the parks due to OSVs.

1.1. Motivation for study

The National Park Service (NPS) Organic Act is the fundamental law guiding national park management. The Organic Act mandates that national park resources be protected in an unimpaired condition while concurrently allowing for their enjoyment. Since 1990, the NPS has been increasingly concerned about the winter use of Yellowstone and Grand Teton National Parks, and the John D. Rockefeller, Jr. Memorial Parkway (henceforth collectively referred to as the parks). A particular concern is the increased use of snowmobiles in the parks and various legal actions brought by environmental, recreational, governmental, and commercial groups. The NPS has conducted extensive analysis of the situation, which resulted in the issuance of Winter Use Plans and Environmental Impact Statements (EISs)[7]. Although snowmobiles can facilitate the enjoyment of these parks for many visitors, they can also undermine the experience for others and impair the condition of park resources; therefore care must be taken in determining acceptable snowmobile use in the parks. In order to try to maintain a balance between the positive and negative effects of snowmobile use in the parks, Winter Use Plans have been developed which include various snowmobile restrictions including: no use, limited use, guided use, and the use of so-called "Best Available Technology (BAT)" snowmobiles. Winter use of snowmobiles in the parks is currently under judicial review[a]. As an aid to the decision making process, several technical reports on snowmobile use in the parks have been written[8, 9, 18, 19]. These studies consist of extensive measurements of sound sources and have made use of the Federal Highway Administration (FHWA) Traffic Noise Model (TNM)[10, 11] to model sound levels at various distances.

1.2. Objectives

The NPS is currently evaluating several modeling alternatives to determine the economic, acoustic, and air quality impacts of various management strategies to control the number, type, and operation of OSVs in the parks for their development of Winter Use Plans. The objectives of the present study are to aid the NPS in their development of Winter Use Plans for the parks by:

- performing acoustical modeling of six modeling alternatives[b], as well as the current and historical conditions (henceforth referred collectively as modeling alternatives);
- providing percent time audible contours;

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[a] Yellowstone National Park, "Winter Use Technical Documents," http://www.nps.gov/yell/technical/planning/winteruse/plan/wlraorder.pdf, 21 Aug 06.

[b] There are six modeling alternatives, 1 through 6, however, alternative 1 includes 4 options, namely A, B, D, and E. Option C was not modeled because the C's operations were adequately modeled by Option D and E.

- providing A-weighted level distributions at National Park Service specified locations throughout the parks, i.e., determining percent time between 0 to < 5, 5 to < 10, 10 to < 15,… dB(A) at each location;
- providing a rank ordering based on park area affected by 50 percent time audible.

In addition to these core objectives, recommendations for future work will be given.

1.3. Scope

Acoustical modeling was performed by using the Federal Aviation Administration's (FAA) Integrated Noise Model (INM) Version 6.2[12, 13], adapted for use with OSVs. In a recent study, the Federal Interagency Committee on Aircraft Noise (FICAN)[14, 15] concluded that Version 6.2 was best suited for modeling aircraft noise in the National Parks. A significant advantage of INM Version 6.2 is that it allows for direct calculation of Percent Time Audible, a metric that has been found to correlate well with interference to visitor experience[16]. In order to model OSV use, the ground-to-ground propagation algorithm in Version 6.2 was modified to better account for sound propagation over snow-covered terrain. This modification was based on the physical acoustics algorithm in the Federal Highway Administration's (FHWA) Traffic Noise Model (TNM). Further discussions of the TNM, the INM, and of modifications to the INM are presented in Appendix A.

Modeling of OSVs in a complex environment involves many variables which can affect the results and which cannot always be controlled. Examples of factors affecting sound at an observer's location due to an OSV include; terrain profile and ground cover, ambient sound levels, vehicle grouping and spacing, temperature, humidity, vehicle type, sound source location, path and speed of vehicle, speed variations (i.e., acceleration/deceleration), vehicle loading, wind speed and direction, snow hardness, snow depth and snow moisture content. Even repeated measurements at close distances over flat terrain can show noticeable variation[17]. Several important modeling assumptions were made in this study, including modeling for temperature, relative humidity, and snow cover representative of an average day during the winter season in the parks (see Section 2 and Appendix A), no wind, and constant operational speed over a given path segment. Vehicle grouping and hourly distributions were prescribed by the NPS. The choice of an 8-hour day was also made based on recommendations by the NPS.

The INM requires as input: ambient sound level maps, tracks (in this case OSV tracks), operations data, and sound source characteristics. Since the A-weighted sound levels and unweighted, one-third octave-band levels of a large number of snowcoaches and two- and four-stroke snowmobiles have been measured in previous studies[8,9], the current study uses these data. Similarly since the NPS has conducted extensive winter measurements of ambient sound levels in the parks[18, 19], these data were used for developing the ambient maps. Additional assumptions will be discussed as needed.

1.4. Organization

This document begins with an executive summary and a glossary of terminology. Section 1 provides a brief summary of the motivation and objectives for the study. Section 2 gives an overview of the two study parks. Section 3 gives details on the various model inputs. Results and analysis of the modeling are presented in Section 4. Conclusions and recommendations are given in Section 5. Supporting data is presented in the appendices. Appendix A discusses the adapted version of INM 6.2. Appendix B includes data and analysis supporting natural ambient sound level maps. Appendix C includes data and analysis supporting OSV sound source data. Appendix D contains detailed development of the hourly operations used in INM for the modeling alternatives. These operations were developed from the daily operations, peak and off-peak hours, and guide requirements provided by National Park Service. Appendix E contains the percent time audible contour maps for the modeling alternatives. Appendix F contains results from the percent time above A-weighted level computations. Appendix G contains supplementary A-weighted and time audible contour maps for previous modeling scenarios used during initial modeling development.

2. Park Overview

Yellowstone (Figure 7) and Grand Teton National Parks (Figure 8) are connected by the John D. Rockefeller Jr. Memorial Parkway. Yellowstone covers 2,219,789 acres of land and is larger than Rhode Island and Delaware combined. Grand Teton covers about 310,000 acres and the John D. Rockefeller Jr. Memorial Parkway covers 23,700 acres. The highest point in the parks is Grand Teton with an elevation of 13,770 feet. Jackson Lake in Grand Teton has an elevation of 6,775 feet.

The parks contain lakes, rivers, coniferous forests, grasslands, waterfalls, hot springs, and geysers. These types of landcover all affect the ambient sound levels as well as the sound propagation. Waves breaking against the lake shore, water rippling over rocks, and wind blowing through trees and scrub all generate sound which contributes to the ambient sound levels. In winter much of the park is covered by snow, which can greatly affect how sound propagates. In most cases, snow-covered terrain can be characterized as acoustically absorptive, that is, it will attenuate sound to a large degree. The one exception is snow-covered terrain that has iced over. Yellowstone land cover includes approximately 5% water, 15% grassland, and 80% coniferous forest. Open areas and forested areas are more evenly distributed in Grand Teton. The exact percentages are somewhat variable due to controlled and uncontrolled forest fires.

In addition to the presence of snow, the winter months have specific effects on sound absorption associated with the temperature and relative humidity. In general, atmospheric absorption increases with increasing temperature and decreasing humidity. The average temperature[a] is 16.8 ˚F during the winter season with a relative humidity[b] of 73.9% for the parks.

For modeling, ambient sound levels are determined by acoustic zones, which are discussed in Section 3.

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[a] ftp://ftp.wcc.nrcs.usda.gov/data/climate/table/temperature/history/wyoming/

[b] Jackson Hole airport

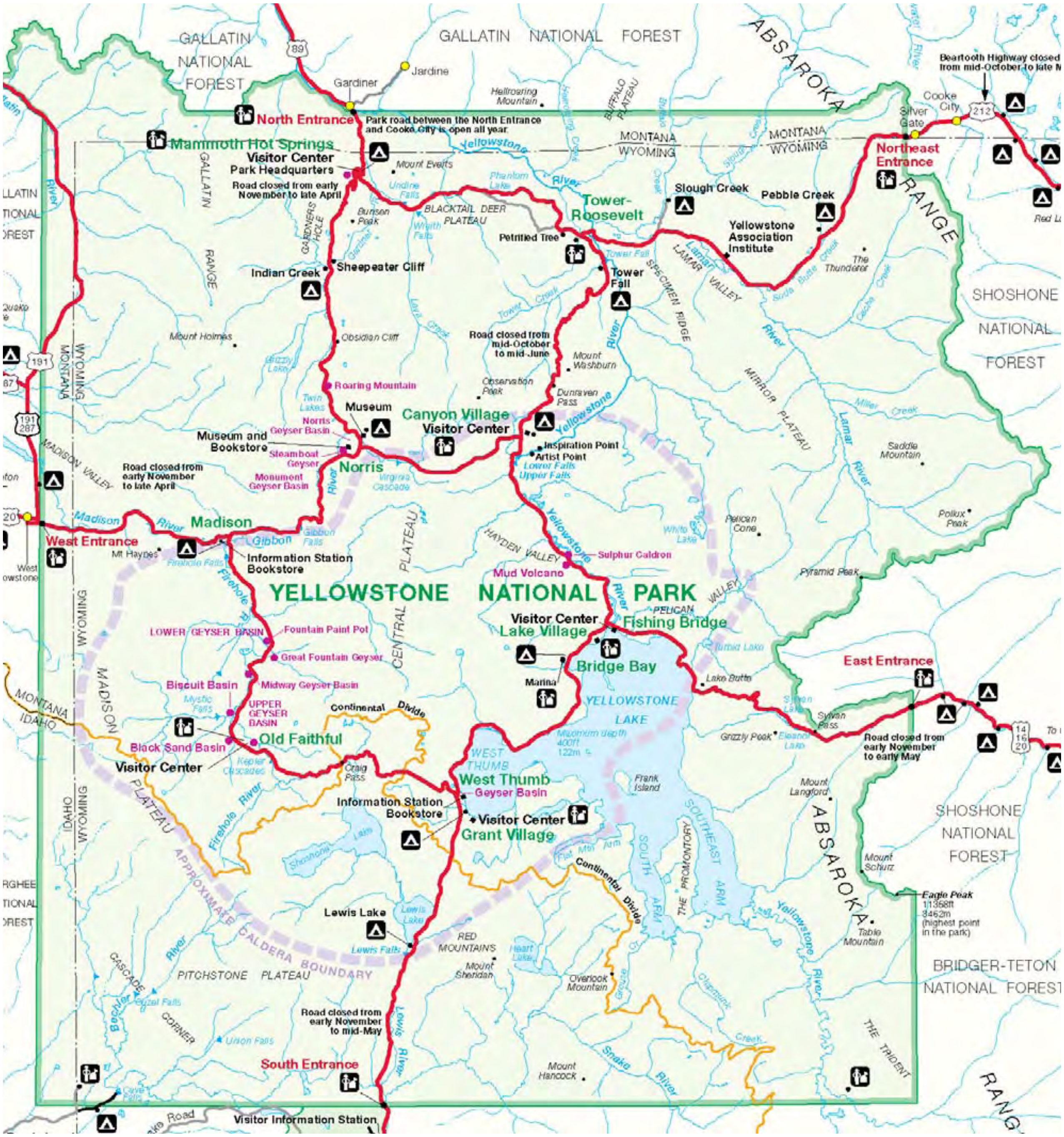

Figure 7: Yellowstone National Park ref: http://home.nps.gov/applications/hafe/hfc/carto-detail.cfm?Alpha=YELL#, accessed 26 September 06.

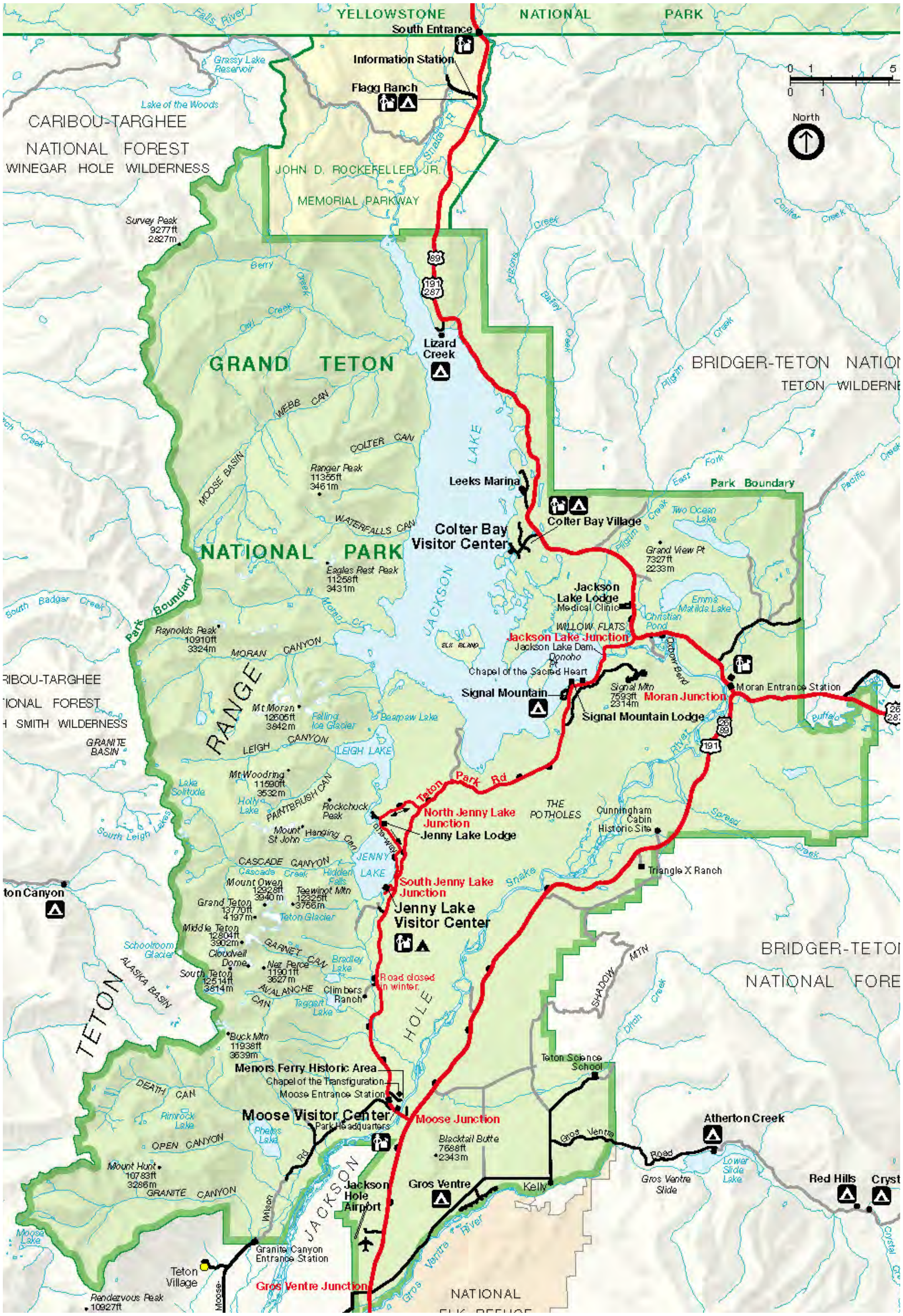

Figure 8: Grand Teton National Park and John D. Rockefeller Jr. Memorial Parkway ref: http://home.nps.gov/applications/hafe/hfc/carto-detail.cfm?Alpha=GRTE#, accessed 26 September 06.

3. Model Inputs

For the purpose of this study, data entered into the INM can be organized into four groups: ambient, source, track/operation, and scenario data. Ambient sound levels are used in the calculation of time audible, which evaluates audibility based on comparisons of the source, the ambient, and auditory system noise levels. Sound source levels and spectral profiles affect how far sounds propagate from sources. Generally, high levels and low frequencies travel further than low levels and high frequencies. Track and operational data determine sound source (vehicle) paths and how fast they travel. Scenarios determine how many sources travel along a given path. In general, the closer the proximity, the faster the speed, and the greater the number of vehicles, the greater the sound level at a receiver location (and usually the greater the audibility over distances). Extensive acoustical measurements have been made of OSVs and ambient sound levels by Harris Miller Miller & Hanson (HMMH) and the NPS. These data were relied upon to model source emissions and natural ambient sound levels in the parks. For completeness these data are summarized here.

3.1. Ambient Sound Level Data: Acoustic Zones to Natural Ambient Maps

To develop ambient maps for this study, acoustic zones were defined and sound measurements made in accordance with various protocols[20]. After post processing removed all manmade sounds for the total existing ambient, estimates of the natural ambient were assigned to broad acoustic zones based on measurements made at a representative location for that zone, the final result being the natural ambient map. The subsequent four sections discuss in more detail the development of the ambient maps used in the modeling.

3.1.1. Acoustic Zones

Acoustic zones are areas with similar land cover, topography, elevation, and/or climate. (These characteristics affect acoustic propagation.) It is assumed that similar fauna, physical processes, and other sources of natural sounds occur in a given acoustic zone. These characteristics affect ambient sound levels. Thus, areas within the same acoustic zone would be expected to have similar natural acoustic characteristics. For further discussion of acoustic zones in general, see Reference 20.

In the winter, the majority of the parks' land cover can be categorized as either open (frozen lakes and grasslands) or forested. Therefore, two primary acoustic zones were defined for this study, open and forested. In addition to these two main zones, a third acoustic zone was defined to account for small areas of human development. Although these human developed areas are physically small, they possess the potential to have significantly different ambient sound levels compared to forested or open acoustic zones. Figure 9 shows the locations of these acoustic zones for Yellowstone.

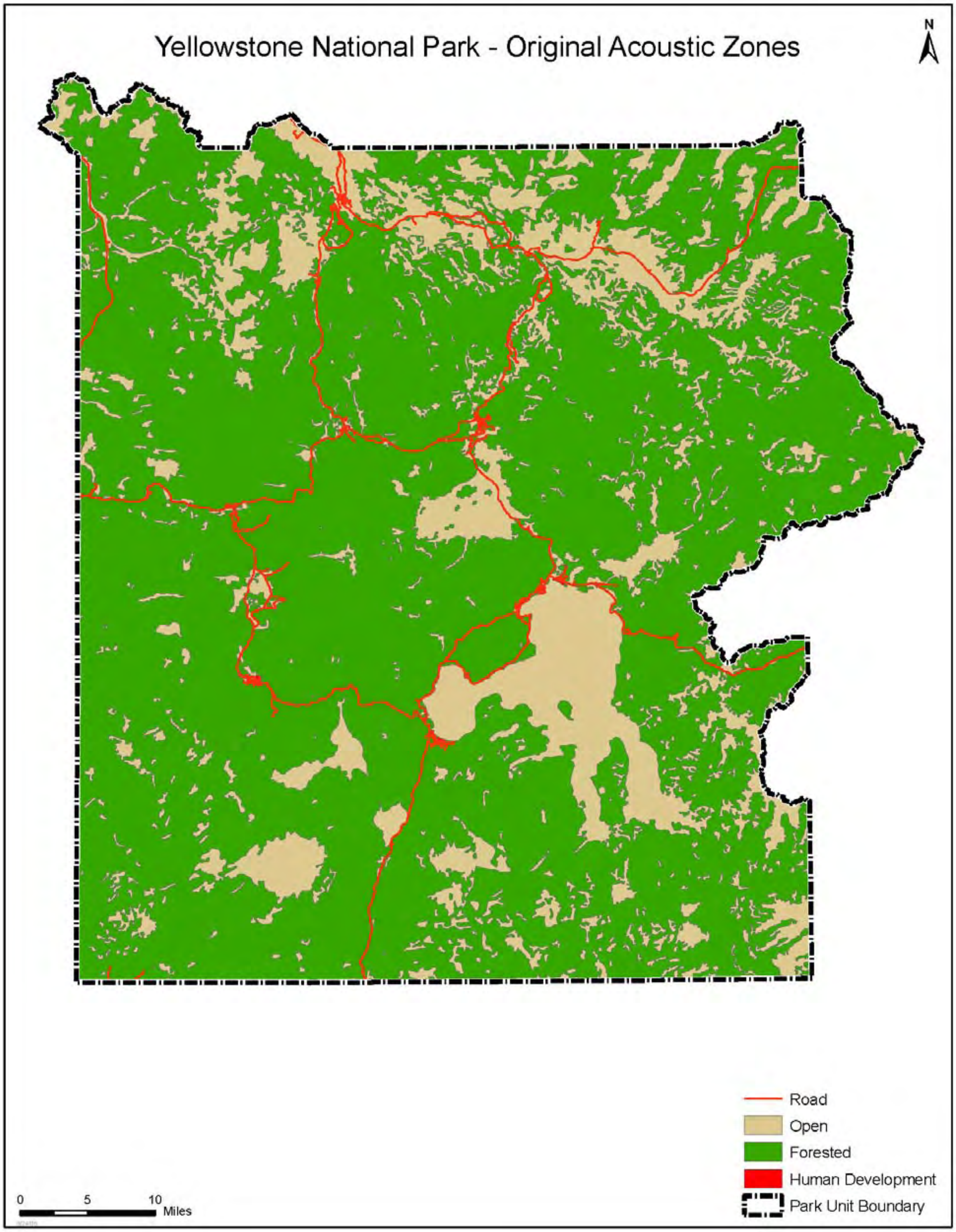

Figure 9: Yellowstone acoustic zones based on land cover before simplification

As shown in Figure 9, although there were only three acoustic zones, their dispersion throughout the park yielded a large number of polygons. Merging small areas into surrounding zones was an efficient method to simplify the many zones to a manageable number while still retaining a high level of polygonal boundary detail. To do this, three criteria were used. 1) Any polygon that was less than 1000 acres was merged into the surrounding polygon. 2) Any additional small polygons that did not match the general pattern of land cover distribution and were at least 5 miles from road sources were merged. 3) Most polygonal regions do not have proper names, i.e., they are simply either an open, forested, or human development region. However, some areas are sufficiently unique that they have been given proper names by the NPS, e.g., Fir Ridge, Bechler Meadows, and Little Firehole Meadows. Based on feedback from the NPS, polygons with proper names were maintained. Applying these three criteria to the parks produced the simplified acoustic zones used in this study. The original and simplified acoustic zones for Yellowstone are shown in Figure 9 and Figure 10. The simplified acoustic zones for Grand Teton and John D. Rockefeller Jr. Memorial Parkway are shown in Figure 11. This merging was conducted with feedback from the appropriate NPS expertise.

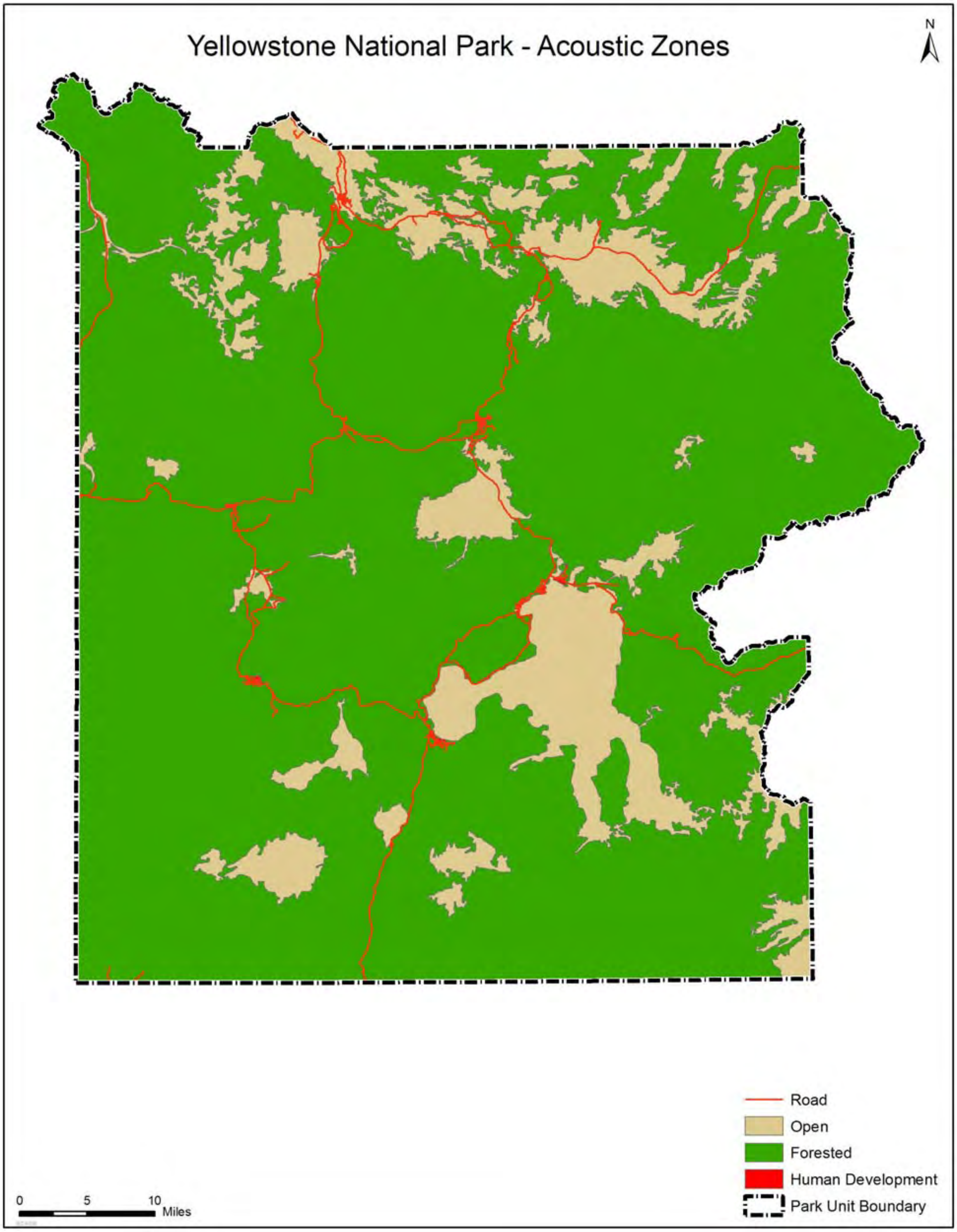

Figure 10: Yellowstone acoustic zones based on land cover after simplification

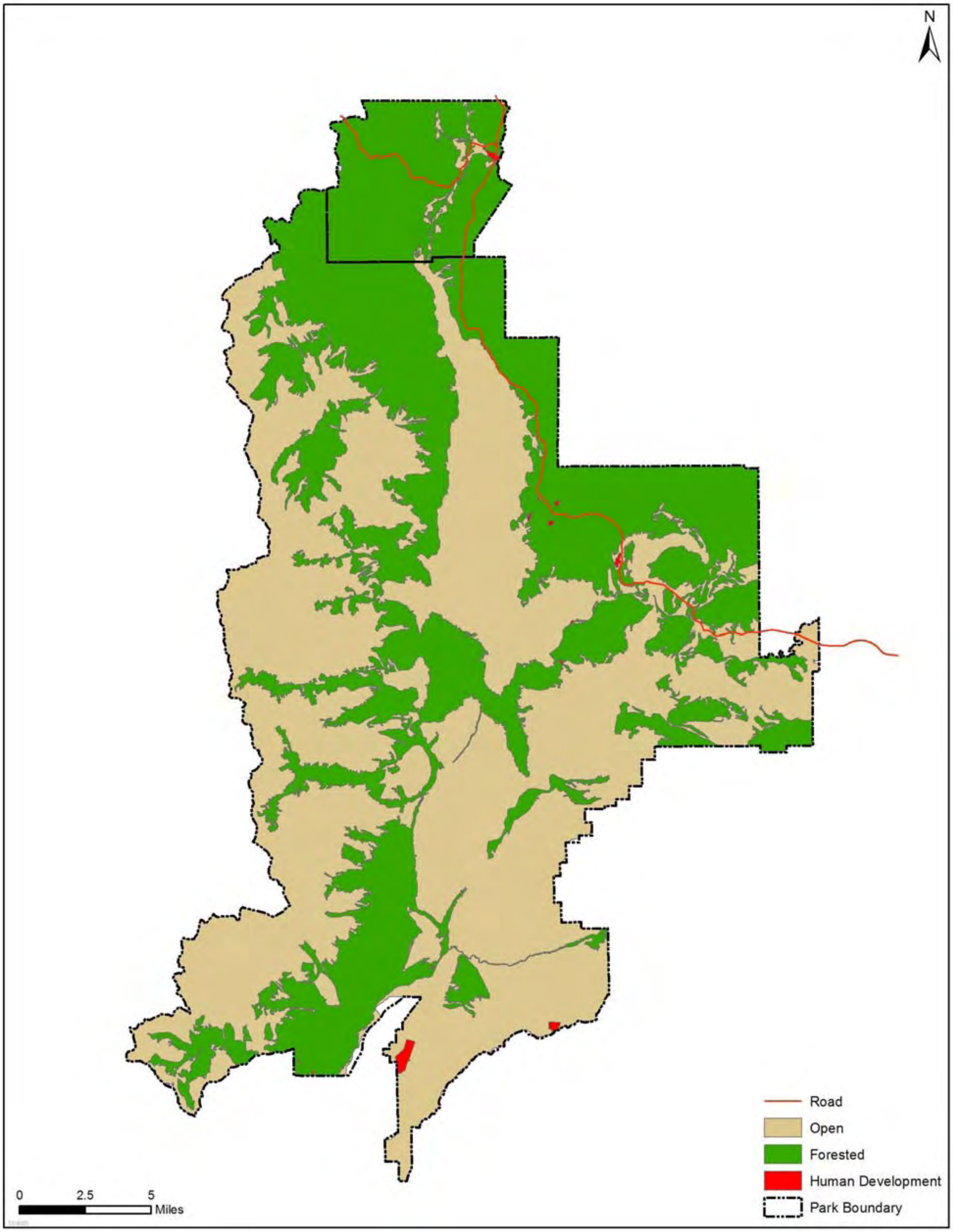

Figure 11: Grand Teton and John D. Rockefeller Jr. Memorial Parkway acoustic zones based on land cover after simplification

3.1.2. Ambient Sound Level Measurements

Personnel from the NPS performed acoustic measurements in the parks over several winters. These measurements were intended to provide acoustical data related to human-based noise sources, but also include intervals without human noise sources. These intervals were used to develop estimates of the natural ambient sound levels in the parks. The NPS recorded one-second Sound Pressure Levels (SPL) continuously and ten-second acoustic pressure signals once every four minutes. Additionally a trigger was set to record twenty-second time histories whenever a specified sound level threshold was exceeded. Equipment used included: Larson Davis Model 824 sound level meters, Model PRM902 microphone preamplifiers, GRAS Model 40AE microphones with windscreens, B&K Model 4231 and Larson Davis Model LD200 calibrators, and a Larson Davis Model ADP004 microphone simulator. Measurements were made over three winter seasons (2003, 2004, and 2005). Estimates of the one-third octave-band levels for center frequencies from 50 Hz to 10 kHz were made by using data measured during the months, January and February, and during the day, 8:00 A.M. to 4:00 P.M. Measurement site locations are listed in Appendix B, Table 14 and Table 15. Further details of ambient sound level measurements can be found in References 18 and 19.

3.1.3. Natural Ambient Sound Levels

Table 1 summarizes the natural ambient sound levels for open and forested areas of Grand Teton as provided by NPS. Due to a lack of ambient data for Yellowstone, the ambient sound levels from Grand Teton were applied to the acoustic zones in both parks. This is believed to be reasonable based on the proximity, habitat similarity, and acoustical similarity between Yellowstone and Grand Teton, particularly in the winter months.

Table 1: Natural ambient sound levels

	One-Third Octave Band Center Frequency, Hz											
Acoustic Zone	50	63	80	100	125	160	200	250	315	400	500	630
Open, dB	13.65	12.45	12.90	12.50	11.90	10.65	10.40	10.45	9.70	8.45	7.20	5.05
Forested, dB	6.20	6.40	6.30	6.30	4.70	4.70	5.50	5.20	3.80	1.90	0.50	-1.20

Acoustic Zone	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	Total, dB(A)
Open, dB	2.70	1.85	2.20	2.85	3.80	4.60	5.30	6.10	7.05	8.00	9.25	10.55	21.65
Forested, dB	-1.40	-0.80	-0.10	0.90	1.80	2.70	3.70	4.70	5.30	6.10	7.10	7.00	15.40

It should be noted that the natural ambient was quite low, which is common in winter months and in remote areas within national parks when wildlife activity typically decreases. During the measurement calibration process, the instrument noise floors were measured by replacing the microphone with a microphone simulator. Example instrument noise floors are shown in Figure 37 and Figure 38 in Appendix B. Ideally, the measured sound levels should be several dB above the instrument noise floor in order to make sure that the instrument noise floor does not contaminate the measured data. In some one-third octave-bands the instrument noise floor is very close to the measured ambient sound level. If the sound from the OSV is less than the threshold of hearing, i.e., the Equivalent Auditory System Noise (EASN), then it will not be audible regardless of the ambient sound level[14]. In most of the bands where the difference between ambient and instrument noise floor are small, the EASN is actually greater than both, therefore, the audibility results should not be significantly affected by the relatively low ambient sound levels. Further discussion of the instrument noise floor can be found in Appendix B.

3.1.4. Natural Ambient Maps

The computed natural ambient values presented in Table 1 were then assigned to the appropriate polygons associated with each acoustic zone, open or forested. At present, ambient sound levels are not available for the human developed acoustic zone. For this study, the human developed polygons were assigned the same ambient sound levels as the forested acoustic zone. Because ambient sound levels will typically be higher in developed areas, audibility estimates in the human developed areas will be conservative, i.e., overestimated. The resulting natural ambient maps are shown in Figure 12 and Figure 13 for Yellowstone and Grand Teton, respectively.

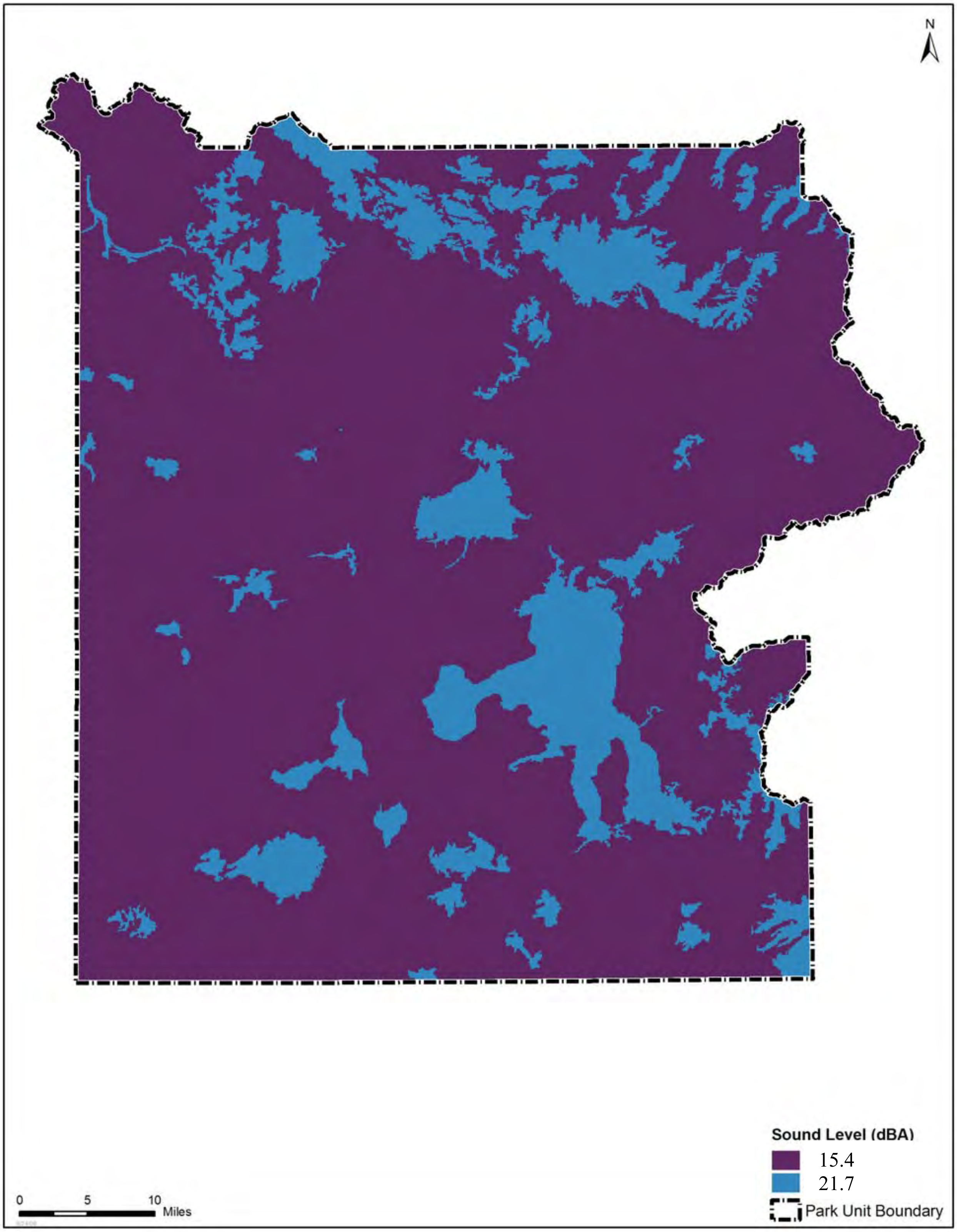

Figure 12: Yellowstone natural ambient map

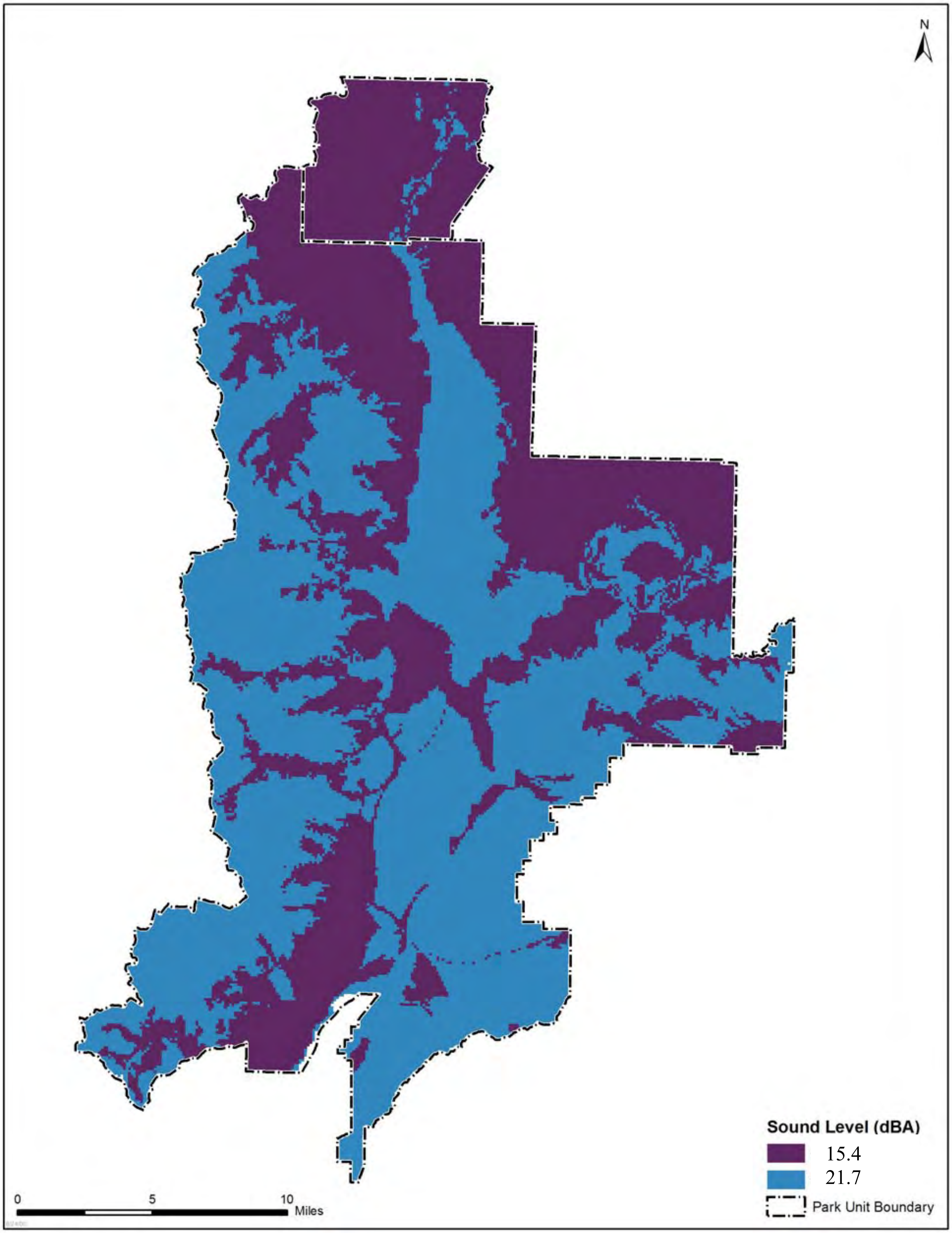

Figure 13: Grand Teton natural ambient map

3.2. Source Data: Sound Levels, Spectral Classes, and Noise-Speed-Distance Curves

Spectral classes account for frequency-dependent propagation effects, e.g., atmospheric absorption. Source data provided by NPS were used to develop OSV-specific spectral classes, in addition to Noise-Speed-Distance (NSD) relationships. NSD relationships are a slightly modified version of the INM's standard Noise-Power-Distance relationships. The noise levels in the NSD relationships will always decrease with increasing distance and will typically increase with increasing speed.

3.2.1. Sound Source Levels and Spectra Measurements

The source data were derived from two previous NPS reports[8, 9]. A summary of these data is provided here for ease of reference. Measurements were made on an open section of snow-covered road just south of Yellowstone's south entrance. The road was groomed but the rest of the measurement site was covered with soft, light, unpacked snow between 36 and 40 inches deep[9]. See Figure 14. The measurement procedures were based on the Society of Automotive Engineers (SAE) standards SAE J192[21] and J1161[22] but were modified as follows: the sound level meters were set for "fast" time response, vehicles passed-by with constant speeds targeted at 20, 35, and 45 miles per hour for snowmobiles and 20 and 30 miles per hour for snowcoaches. Equipment used included: B&K Model 4189 microphones, Larson-Davis Model 900B microphone preamplifiers, Larson-Davis Model 870 sound level meters, GenRad Model 1987 sound level calibrators, and a Sony Model TCD-D8 DAT recorder. A-weighted sound levels were recorded every 1/8th second. One-third octave-band data were calculated by post-processing the time histories stored on the DAT tapes.

Figure 14: Measurement site for vehicle acoustic source measurements, Reference 9

The raw data from References 8 and 9 were not available to directly support this study. So, they were recovered directly from the report by digitizing applicable graphical data. Maximum A-weighted sound levels during pass-bys and unweighted one-third octave-band data were obtained for five, four-stroke snowmobiles; ten, two-stroke snowmobiles; and fourteen snowcoaches. Sound exposure level data were not available. The digitized data are listed Appendix C in

Table 16 and Table 17. Examples of the types of vehicles measured are shown in Figure 15 through Figure 17. Additional samples are shown in Appendix C Figure 40 to Figure 42.

Figure 15: Polaris frontier snowmobile with four-stroke engine, Reference 9

Figure 16: Yellow Bombardier snowcoach with high exhaust[a]

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[a] Reference the National Park Service, "Yellowstone Winter Vehicle Use and Air Quality", http://www2.nature.nps.gov/air/Studies/yell/20042005yellAQwinter.cfm, Photo by J. Ray, August 29th, 2006.

Figure 17: Two-track / full-track / Snow Buster conversion van snowcoach, Reference 9

3.2.2. Spectral Classes

Spectral classes were determined based on vehicle, engine, and track type. As a first step in the analysis, data were grouped by snowcoach or snowmobile. Snowmobiles were divided by engine type: two-stroke or four-stroke. Snowcoaches were divided by purpose-built (Bombardiers[a]) or modified conversion vans. Conversion vans were further divided into two-track (Snow Busters[b]) and four-track models (Mattracks[c]). The spectral class division scheme is illustrated in Figure 18. The one-third octave-band levels for each spectral class are given in Table 2.

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[a] Bombardier was a manufacturer of a purpose built snowcoach. Two versions of this snowcoach are used in Yellowstone. One has raised exhausts and is shown in Figure 16. One has low exhausts and is shown in Figure 41 (Appendix C). Standard and raised exhaust models were logarithmically averaged when modeling average spectra (for spectral classes and ground effects) for these snowcoaches. The raised exhaust model was used for determining spectra at different speeds (for Noise–Speed–Distance relationships) since insufficient speed related data was available for the standard exhaust.

[b] Snow Buster is a two-track (also called full-track) snowcoach brand name. These conversion vans have two large tracks in the rear and skis in the front. See Figure 17.

[c] Mattracks is a four-track snowcoach. These conversion vans have four triangular shaped tracks, one in each wheel well. See Figure 42.

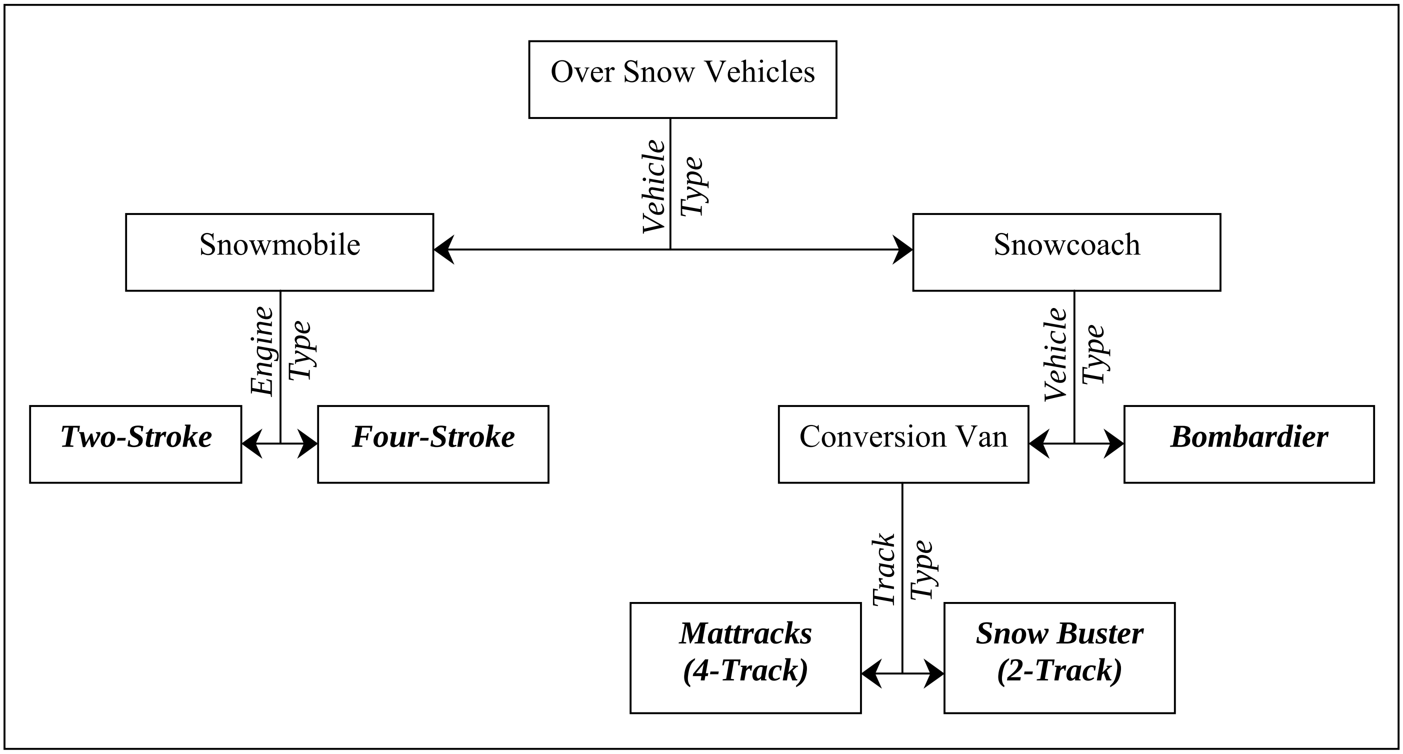


Figure 18: Spectral class division scheme

Table 2: One-third octave-band levels used for INM's spectral classes

	50	63	80	100	125	160	200	250	315	400	500	630	Hz
SM 4-Stroke	51.2	51.8	69.4	68.8	65.0	67.1	63.2	66.1	67.2	67.3	66.1	65.1	dB
SM 2-Stroke	53.3	53.7	54.8	61.8	56.6	56.7	67.6	65.4	66.7	66.0	67.3	61.4	dB
Bombardier	61.2	66.2	65.4	73.1	64.0	64.3	64.6	62.8	63.9	58.7	60.3	61.1	dB
Mattracks	57.3	63.6	58.3	64.8	69.4	66.1	66.8	75.1	71.0	67.5	63.9	62.7	dB
Snow Buster	55.3	56.8	57.6	58.6	63.4	60.1	61.5	61.1	59.7	59.9	58.0	58.2	dB

	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	Hz
SM 4-Stroke	59.4	58.5	60.0	60.0	61.2	60.2	58.3	56.6	53.8	51.5	48.1	44.4	dB
SM 2-Stroke	60.8	63.3	63.7	64.8	64.6	61.6	58.9	58.0	56.5	53.6	49.9	47.4	dB
Bombardier	62.2	60.3	60.2	59.1	57.4	56.6	55.6	55.3	56.4	55.3	51.7	44.8	dB
Mattracks	64.2	65.0	63.2	63.3	61.4	60.1	56.8	53.5	51.9	49.7	48.1	46.3	dB
Snow Buster	58.6	58.7	60.2	59.8	58.2	55.1	51.9	48.5	45.3	43.0	40.8	37.2	dB

3.2.3. Noise-Speed-Distance Relationships

NPD relationships are the starting point for INM's propagation algorithms. However, for OSVs, speed is a more appropriate parameter than power. Therefore, a modified set of Noise-Power-Distance relationships was used, whereby speed replaces power, giving Noise-Speed-Distance (NSD) relationships. These NSD relationships are developed by modeling the effects of spherical dispersion[23] and frequency dependent atmospheric absorption[24]. In previous studies, acoustic measurements of snowcoaches were made for speeds from 10 to 35 miles per hour and snowmobiles from 15 to 40 miles per hour.

For the purpose of acoustical modeling of snowmobiles, four-stroke snowmobiles represent the BAT. There was limited availability of sound level data for four-stroke snowmobiles during previous studies, specifically, data were only available for speeds of 30 and 40 miles per hour and these data came from a limited number of vehicles. Also, because these studies were based on older four-stroke vehicles, they do not necessarily represent the current BAT[8]. Finally, these measurements indicated that four-stroke snowmobiles had slightly higher levels at 30 mph, 77.6 dB(A), than at 40 mph, 71.5 dB(A), which was somewhat counter-intuitive. Therefore, in order to better quantify the current sound levels of the BAT snowmobiles in the Parks' fleet, the National Park Service made additional measurements of four-stroke snowmobiles over the 2005-2006 winter season in a manner similar to the SAE J192 and J1161 standards.

Because the previous modeling of the four-strokes in the INM was based on the constant speed measurements (J1161), the 2005-2006 measurements that were based on the J1161 standard were used to replace the older measured levels in the NSD table. These consisted of fifteen measurements at 15 mph, fifty-four measurements at 30 mph, and eighteen measurements at 40 mph. Where the current measurement speeds coincided with previous measurement speeds, there was an average level decrease of about 5.6 dB(A). See Figure 19. The NSD relationships developed for all vehicle types are shown in Table 3, where the four-stroke levels are based on the 2005-2006 winter season.

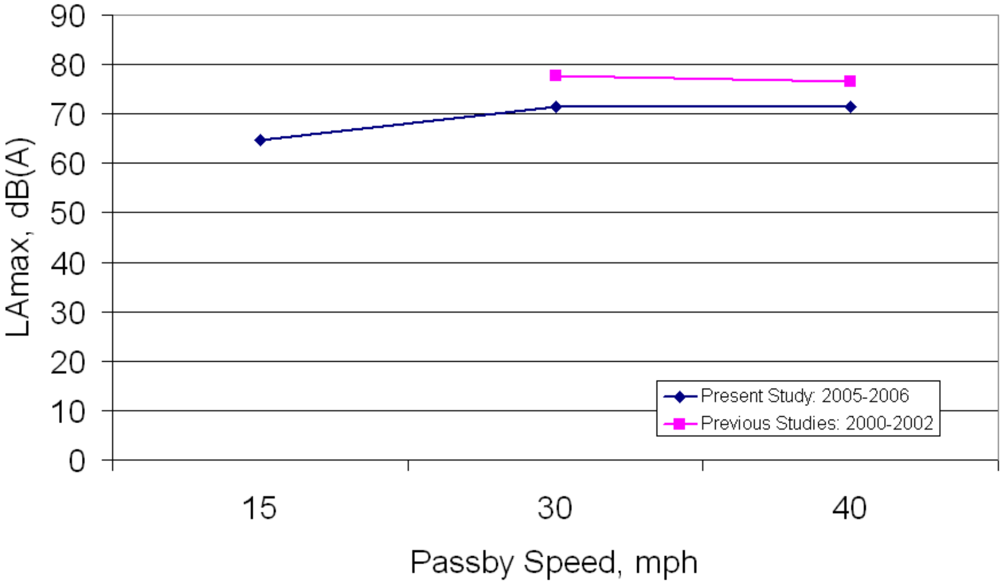


Figure 19: Comparison of BAT snowmobile sound levels from previous and present studies.

Table 3: Noise-Speed-Distance. Each column represents a different OSV and speed in mph. Each row is a different distance between source and receiver in feet.

		L_{Amax}																				
	Vehicle	Two-Stroke Snowmobile				Four-Stroke Snowmobile			Bombardier Snowcoach			Snowbuster Snowcoach				Mattracks Snowcoach			Van - Wheeled			Bus - Wheeled		
	Speed, mph	10	20	35	40	15	30	40	15	20	35	10	15	20	35	10	20	35	30	35	40	30	35	40
Distance, feet	200	54.5	59.2	60.7	62.1	48.3	52.8	55.1	52.4	58.7	64.1	53.1	51.2	56.5	60.4	48.8	55.0	59.1	50.1	52.8	55.2	61.0	62.2	63.4
	400	47.9	52.4	53.8	55.4	41.6	46.2	48.4	45.9	52.1	57.4	46.4	44.2	49.5	53.7	42.0	48.4	52.6	43.4	46.1	48.4	54.3	55.5	56.6
	630	43.3	47.7	49.1	50.9	36.9	41.7	43.8	41.5	47.7	52.8	41.8	39.4	44.7	49.1	37.4	44.0	48.2	38.8	41.4	43.8	49.7	50.8	52.0
	1000	38.4	42.6	43.9	46.2	32.1	37.0	38.9	37.0	43.0	48.0	36.7	34.4	39.6	44.2	32.6	39.3	43.5	33.8	36.4	38.7	44.8	46.0	47.1
	2000	30.5	34.3	35.5	38.8	24.5	29.8	31.4	29.8	35.7	40.4	28.1	26.9	31.3	36.3	25.0	31.8	36.2	25.9	28.4	30.6	37.3	38.4	39.4
	4000	21.8	25.0	26.3	30.9	16.5	22.0	23.3	22.3	28.0	32.5	17.8	18.9	22.1	27.8	16.8	23.6	28.3	17.5	19.9	21.9	29.4	30.4	31.3
	6300	15.9	18.7	20.0	25.4	10.7	16.5	17.5	17.1	22.7	27.0	10.6	13.5	15.8	22.1	11.1	17.8	22.7	11.8	14.0	15.9	23.9	24.9	25.7
	10000	10.1	12.4	13.5	19.1	4.3	10.2	11.1	11.7	16.9	21.2	4.0	7.7	9.4	16.1	4.8	11.3	16.4	5.9	8.0	9.8	18.2	19.0	19.8
	16000	4.3	6.0	6.4	11.9	-2.8	3.2	4.1	6.0	10.6	15.0	-2.4	1.4	3.0	9.6	-2.3	3.9	9.2	-0.2	1.8	3.5	11.9	12.7	13.4
	25000	-1.5	-0.5	-0.8	3.7	-10.1	-3.9	-3.3	0.1	4.0	8.7	-8.8	-5.0	-2.9	3.2	-9.4	-4.1	1.4	-6.1	-4.2	-2.5	5.6	6.4	7.0

In previous modeling, see for example results in Appendix G, 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, it is reasonable because where the validity of the assumption is most important, the assumption is most valid. When the distance between the group and the receiver is small, then the group will be audible regardless of whether or not they are perceived as a point source. When the distance between the group and the receiver is large, then the group will be perceived as a point source. Two, modeling groups as point sources represents a limiting case of the acoustics involved in modeling groups. Vehicles grouped closely together are heard as single event whose time interval of audibility is shorter than if they were all heard as separate events. The spatial limit for a group of snowmobiles is a point source. As snowmobiles get closer together, their levels add to create the total sound level. For example, five snowmobiles with equal levels would have a combined level of about 7 dB greater than a single snowmobile. 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. Further detail on the modeling of groups is given in Appendix A.C.2.

3.3. Operational Data

In addition to sound source data for OSVs, detailed operational data are also necessary for modeling. This includes the path (track) a vehicle travels, its speed of operation, and how many vehicles are traveling in a given group.

3.3.1. Tracks

Tracks model the routes of the vehicles throughout each park. In the winter, most paved roads are not plowed, but rather are groomed for OSV use, and are considered to be “tracks”.

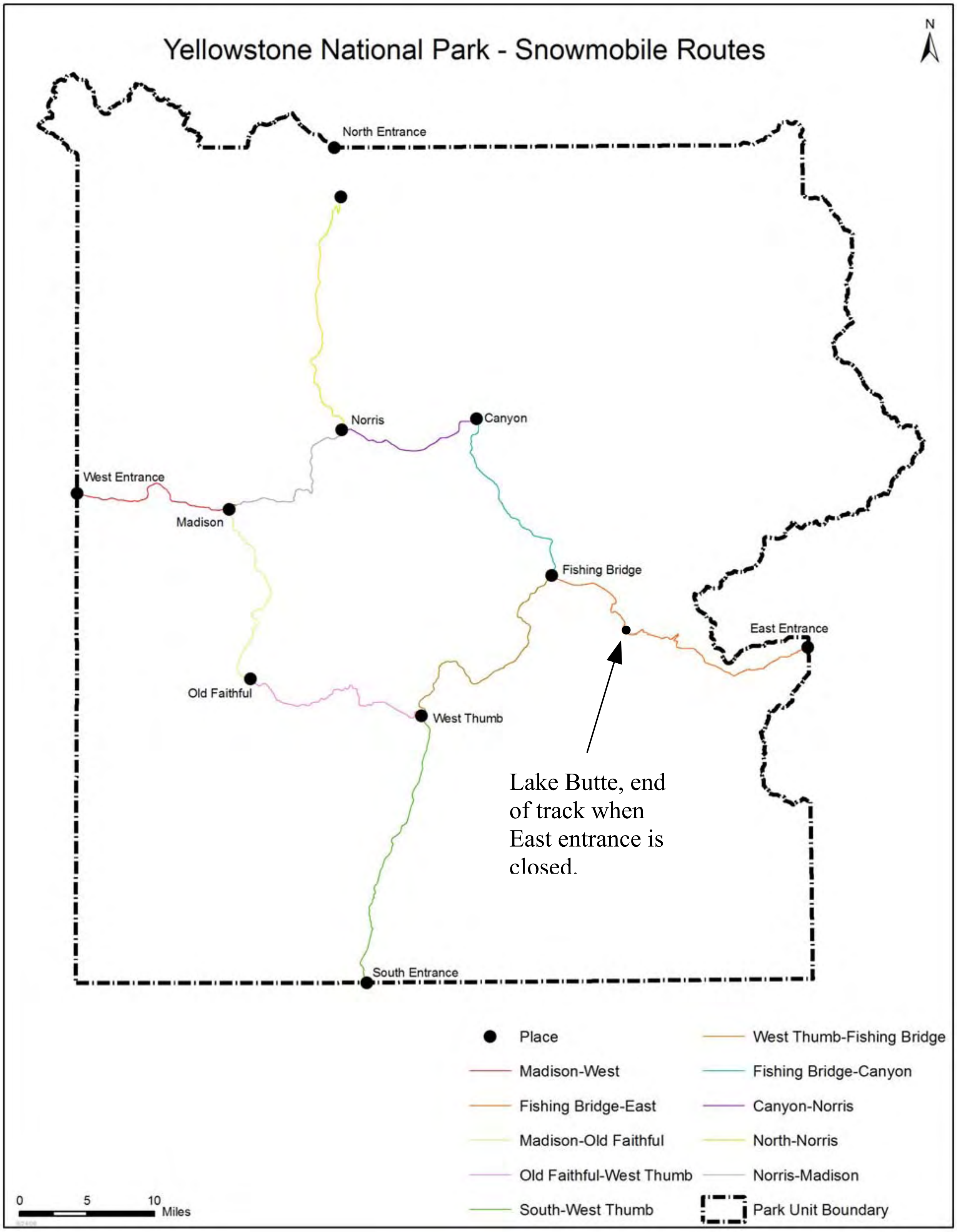
The use of OSVs in Yellowstone is currently limited to the following road segments:

- Mammoth Hot Springs - Norris Geyser Junction,
- West Entrance - Madison,
- South Entrance - West Thumb,
- East Entrance - Fishing Bridge, and
- The central loop Madison - Norris Geyser Junction - Canyon Village - Fishing Bridge - West Thumb - Old Faithful - Madison.

In Grand Teton OSV use is currently limited to:

- Moran Entrance - Flagg Ranch Village,
- Grassy Lake Road, and
- Jackson Lake.

On Jackson Lake, there are two start points, Signal Mountain and Colter Bay. Although a snowmobile may start from either one of these locations, it may travel anywhere on the lake. In order to model this range of potential paths, tracks were delineated based on expert input from the NPS. The tracks for Yellowstone and Grand Teton are shown in Figure 20, Figure 21, and Figure 22.



Lake Butte, end of track when East entrance is closed.

Figure 20: OSV tracks (routes) in Yellowstone National Park

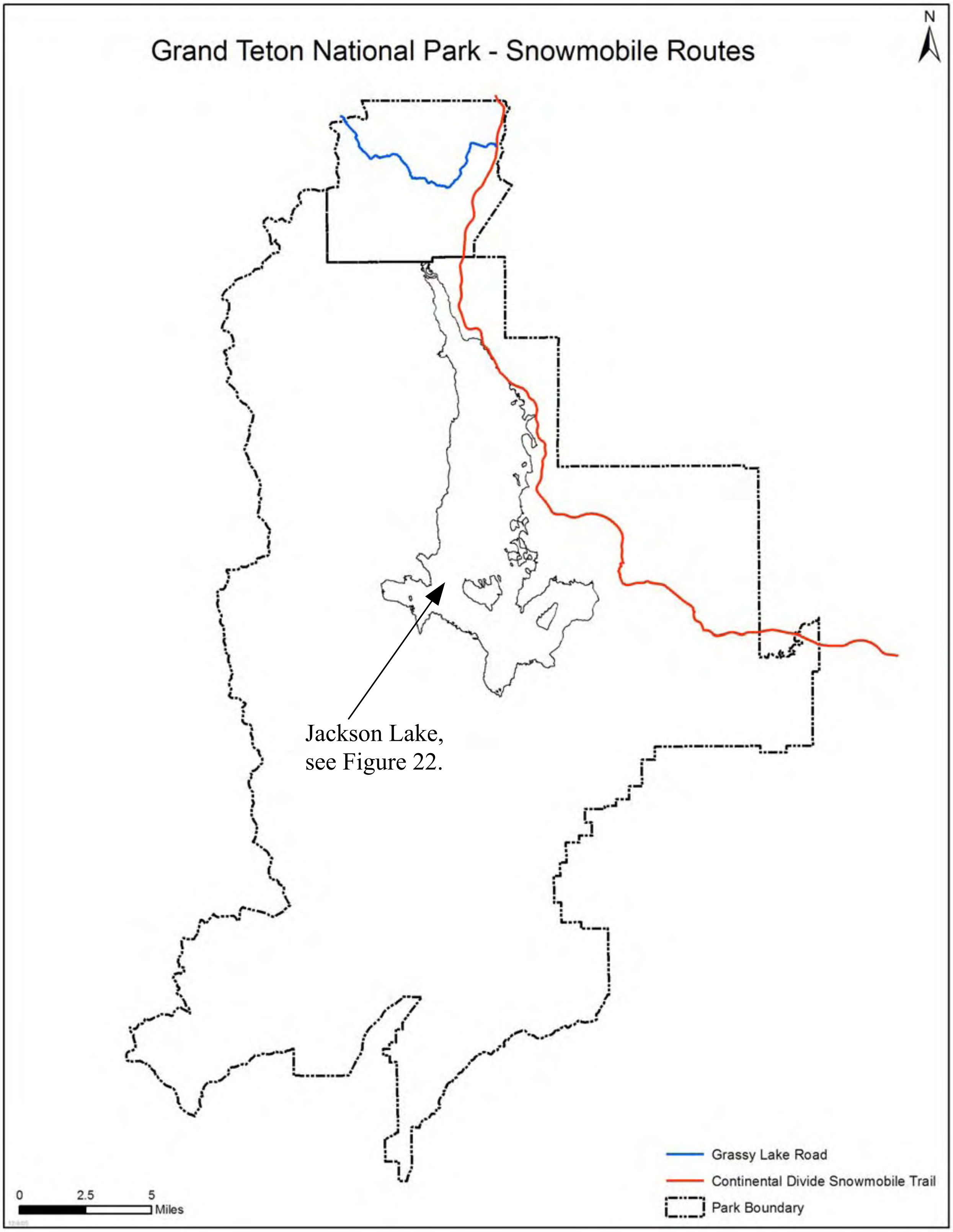


Figure 21: OSV tracks (routes) in Grand Teton National Park

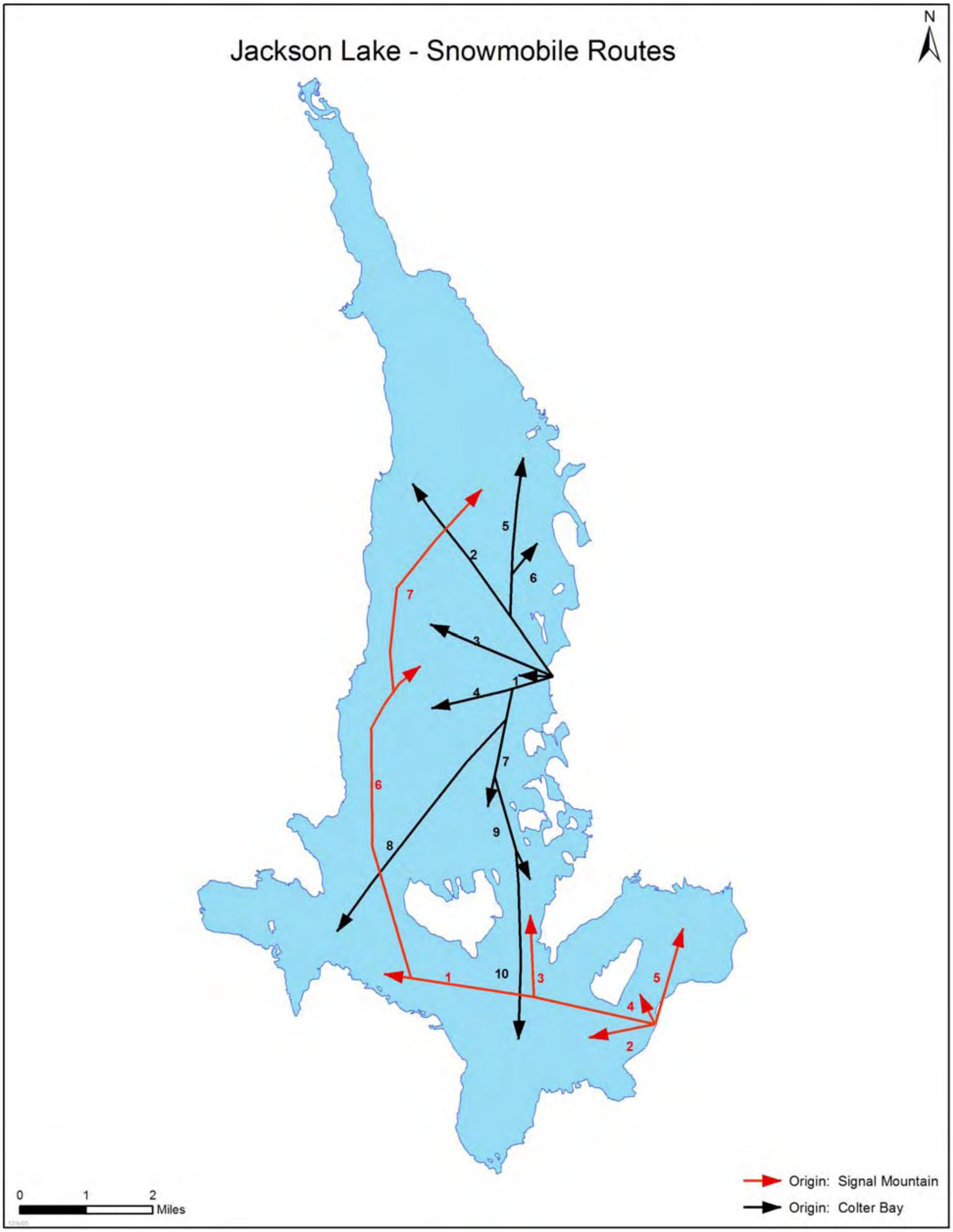


Figure 22: OSV tracks (routes) on Jackson Lake in Grand Teton National Park

3.3.2. Vehicle Speeds

The speeds at which the OSVs were modeled are shown in Table 4. Speeds in the table represent the current speed limits for each path segment. Generally, these speeds are 5 mph below the posted speed limit on each stretch of road.

Table 4: Over-snow vehicle speed limits

Yellowstone road segment	***Average speed, mph (not differentiated by vehicle type)***
Mammoth to Norris	35
West Entrance to Madison	30
Madison to Norris	30
Norris to Canyon Village	40
Canyon Village to Fishing Bridge	40
Fishing Bridge to East Entrance	40
Fishing Bridge to West Thumb	40
Madison to Old Faithful	30
Old Faithful to West Thumb	40
West Thumb to Flagg Ranch	40

Grand Teton road segment	
Moran Junction to Flagg Ranch	25
Flagg Ranch west to boundary	25
Jackson Lake fishing access	25

3.4. Modeling Alternatives

Each modeling alternative was evaluated for an 8-hour day with temperature, relative humidity, and snow cover representative of an average day during the winter season in the parks. Modeling alternatives are labeled 1 through 6 and each was designed to model a particular management alternative. Alternative 1 has five distinct options, A through E, however, C was not modeled because it was sufficiently similar to other alternatives. In addition to the modeling alternatives, current and historical conditions were also modeled. Typically, both snowmobiles and snowcoaches are operated in Yellowstone but only snowmobiles are operated in Grand Teton. Additionally, some snowmobiles enter Grand Teton on the Grassy Lake Road from the Targhee National Forest. These vehicles are typically non-BAT vehicles. A summary of the modeling alternatives as well as current and historical conditions is given below.

- Modeling Alternative 1 (*Continue Temporary Plan*): This alternative continues the current Temporary Plan into the future with some modifications. This alternative limits the number of snowmobiles and snowcoaches according to NPS specifications found in "Preliminary Draft Alternatives – Winter Use Plans"[25], and requires that all vehicles be guided and of Best Available Technology (BAT). This alternative includes several options as follows:
    - Option A: East entrance to Yellowstone open. (Daily Entrance Limit: 720 snowmobiles / 78 snowcoaches)
    - Option B: East entrance to Yellowstone closed for avalanche control. (Daily Entrance Limit: 720 snowmobiles / 78 snowcoaches)

  - Option C: Was not modeled because the operations were adequately modeled by Option D and E[a].
  - Option D: East entrance to Yellowstone closed and reduced over-snow vehicle use. (Daily Entrance Limit: 680 snowmobiles / 78 snowcoaches)
  - Option E: East entrance to Yellowstone and Gibbon Canyon closed, reduced over-snow vehicle use. (Daily Entrance Limit: 680 snowmobiles / 78 snowcoaches)
- Modeling Alternative 2 (*Snowcoaches Only*): This alternative limits over-snow vehicles to BAT snowcoaches only and would also close the East entrance to Yellowstone. Since snowcoaches do not operate in Grand Teton, no modeling was necessary for Grand Teton. (Daily Entrance Limit: 0 snowmobiles / 120 snowcoaches)
- Modeling Alternative 3 (*Eliminate Most Road Grooming*): This alternative eliminates grooming of most roads in Yellowstone and Grand Teton. The exceptions would be the road segment from the South Entrance to Old Faithful and the Grassy Lake Road. These two roads would continue to be groomed. (Daily Entrance Limit: 250 snowmobiles / 20 snowcoaches)
- Modeling Alternative 4 (*Expand Recreational Use*): This alternative would expand the recreational use of the parks during the winter season. For Yellowstone, BAT requirements would remain in place and about 25% of all snowmobiles would be unguided. For Grand Teton, a portion of the snowmobiles on the road segment from Moran to Flagg Ranch would be allowed to be non-BAT. (Daily Entrance Limit: 1025 snowmobiles / 115 snowcoaches)
- Modeling Alternative 5 (*Provide for Unguided Access*): For Yellowstone, BAT requirements would remain in place and about 20% of all snowmobiles would be unguided. This alternative does not increase the number of over-snow vehicles in operation, in contrast to Modeling Alternative 4. (Daily Entrance Limit: 625 snowmobiles / 100 snowcoaches)
- Modeling Alternative 6 (*Mixed Use*): This alternative allows for the use of both over-snow vehicles as well as wheeled vehicles, namely Busses and Vans. The wheeled vehicles would travel on plowed roads on the west side of Yellowstone, whereas the other road sections would be groomed for over-snow vehicle use. (Daily Entrance Limit: 350 snowmobiles / 40 snowcoaches / 100 wheeled vehicles)
- Current Condition: The Current Condition evaluates the level of *use* during the most recent winter seasons. This includes BAT requirements for snowmobiles but not for snowcoaches. The Current Condition also requires guides for all vehicles in Yellowstone, but not for Grand Teton. (Average Daily Entrance[b]: 260 snowmobiles / 29 snowcoaches)
- Historical Condition: The Historical Condition considers a return to the 1983 Regulations guiding winter use in the parks. This would remove limits to visitor use and eliminate Best Available Technology requirements[c]. (Average Daily Entrance: 1400 snowmobiles / 40 snowcoaches)

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[a] Based on “Travel Factors by Alternative_with Exit Factors_22May2006.xls” from the NPS

[b] For Current and Historical Conditions, the estimated average daily entrance numbers are used instead of a prescribed limit. The estimates were provided by the NPS.

[c] The 1983 regulations describe a type and amount of snowmobile use that was found to constitute impairment of park resources and values in the 2000 EIS and the 2003 SEIS.

The 8-hour day was divided into 1-hour periods. The operations for each hour were determined by daily entrance limits, road segment weighting factors, guide requirements, and road segment specific peak usage details. All of these parameters were provided by the NPS. Table 5 shows the daily snowmobile operations for each road segment in Yellowstone. These are based on the daily entrance limits and the road segment weighting factors. Entries marked by an "x" indicate no operations. Table 6 and Table 7 show the daily snowcoach and wheeled vehicle entrance limits for Yellowstone respectively. The daily operations were distributed among the eight 1-hour periods based on guide requirements and peak usage details given in Table 8 and Table 9. (Note, BAT requirements are also included in Table 8. These were used to determine what *type* of OSVs where used.) Similarly, Table 10 and Table 11 were used for determining operations in Grand Teton, however, Grand Teton did not have guide requirements or peak usage specifications. The hourly operations are detailed in Appendix D.

Table 5: Snowmobile Operations (8-hour Day) by Road Segment for Yellowstone[a]

Snowmobiles	1A	1B	1D	1E	2	3	4	5	6	Current	Historical
Canyon Village to Fishing Bridge	323	281	267	164	X	X	501	291	265	109	595
Madison to Old Faithful	737	762	733	843	X	X	1055	641	X	269	1575
Fishing Bridge to East Entrance	84	22	20	20	X	X	186	90	X	21	135
Fishing Bridge to West Thumb	167	166	155	197	X	X	229	139	280	59	275
Madison to Norris	324	315	320	X	X	X	464	300	X	109	676
West Entrance to Madison	744	782	740	752	X	X	1114	629	X	282	1738
Norris to Canyon Village	233	225	225	69	X	X	346	212	15	80	497
Mammoth to Norris	94	71	90	87	X	X	108	118	X	22	129
West Thumb to Flagg Ranch	412	497	430	427	X	500	481	319	460	165	600
Old Faithful to West Thumb	437	476	429	527	X	500	558	351	535	167	728

Table 6: Snowcoach Operations (8-hour Day) by Road Segment for Yellowstone

Snowcoaches	1A	1B	1D	1E	2	3	4	5	6	Current	Historical
Canyon Village to Fishing Bridge	26	23	23	40	37	X	40	33	55	11	14
Madison to Old Faithful	79	80	80	75	123	X	114	102	X	31	42
Fishing Bridge to East Entrance	6	2	2	2	3	X	10	7	X	2	2
Fishing Bridge to West Thumb	10	10	10	35	18	X	16	12	55	4	6
Madison to Norris	38	38	38	X	56	X	53	49	X	16	19
West Entrance to Madison	73	72	72	68	114	X	106	94	X	28	41
Norris to Canyon Village	24	24	24	21	36	X	35	32	3	10	13
Mammoth to Norris	26	25	25	29	34	X	34	33	X	12	10
West Thumb to Flagg Ranch	41	46	46	27	74	40	65	53	21	13	22
Old Faithful to West Thumb	47	51	51	58	79	40	72	61	68	15	24

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[a] Vehicle operations are presented as integers for simplicity here, however, because operations are divided by hours and segments, actual input into INM maintains further precision, see for example Appendix D.

Table 7: Wheeled Operations (8-hour Day) by Road Segment for Yellowstone

Wheeled (Buses and Vans)	1A	1B	1D	1E	2	3	4	5	6	Current	Historical
Canyon Village to Fishing Bridge	X	X	X	X	X	X	X	X	X	X	X
Madison to Old Faithful	X	X	X	X	X	X	X	X	150	X	X
Fishing Bridge to East Entrance	X	X	X	X	X	X	X	X	X	X	X
Fishing Bridge to West Thumb	X	X	X	X	X	X	X	X	X	X	X
Madison to Norris	X	X	X	X	X	X	X	X	69	X	X
West Entrance to Madison	X	X	X	X	X	X	X	X	134	X	X
Norris to Canyon Village	X	X	X	X	X	X	X	X	X	X	X
Mammoth to Norris	X	X	X	X	X	X	X	X	68	X	X
West Thumb to Flagg Ranch	X	X	X	X	X	X	X	X	X	X	X
Old Faithful to West Thumb	X	X	X	X	X	X	X	X	X	X	X

Table 8: BAT and Guide Requirements for Yellowstone by Alternative

	1A	1B	1D	1E	2	3	4	5	6	Current	Historical
SM-BAT	yes	yes	yes	yes	X	yes	yes	yes	yes	yes	X
SC-BAT	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	X
SM Guiding Requirement	100%	100%	100%	100%	X	100%	75%	80%	100%	100%	X
SM Guided Group Size	8, 17	11	11	11	X	11	11	11	8, 17	7	X
SM Unguided Group Size	X	X	X	X	X	X	5	5	X	X	5

Table 9: Peak Usage for Yellowstone by Road Segment

Road Segment	Percent of Total Operations	Peak Hours (Guided)		Percent of Total Operations	Peak Hours (Unguided)
West Entrance to Madison	30%	09:00-10:00		35%	08:00-11:00
West Entrance to Madison	30%	15:00-16:00		40%	15:00-16:00
Madison to Old Faithful	75%	11:00-14:00		75%	11:00-14:00
Old Faithful to West Thumb	75%	11:00-14:00		75%	11:00-14:00
West Thumb to Flagg Ranch	40%	09:00-10:00		30%	09:00-11:00
West Entrance to Madison	40%	15:00-16:00		35%	15:00-16:00

Table 10: Snowmobile Operations (8-hour Day) by Road Segment for Grand Teton

Snowmobiles	1A	1B	1D	1E	2	3	4	5	6	Current	Historical
CDST	100	100	100	100	X	X	150	100	X	X	120
Grassy Lake Rd	95	95	95	95	X	100	143	95	95	38	86
Jackson Lake fishing access	80	80	80	80	X	X	200	80	80	20	120

Table 11: BAT Requirements for Grand Teton

	1A	1B	1D	1E	2	3	4	5	6	Current	Historical
BAT - CDST	100%	100%	100%	100%	X	100%	66.67%	100%	X	100%	X
BAT - Grassy Lake	20%	20%	20%	20%	X	20%	33.33%	20%	20%	X	X
BAT - Jackson Lake	100%	100%	100%	100%	X	100%	100%	100%	100%	100%	X

4. Results and Analysis

This section discusses the results for the six modeling alternatives as well as current and historical conditions for Yellowstone and Grand Teton. Two noise-related metrics were evaluated:

- Percent Time Audible (%TAUD) – The percentage of time that OSV sound levels are audible; and
- Time above A-weighted Sound Level (TALA) – The time in seconds that a given receiver point was above a specified A-weighted Sound Pressure Level.

The %TAUD contour maps are discussed in Section 4.2; the TALA distributions are discussed in Section 4.3; and the overall ranking of the alternatives is discussed in Section 4.4.

When interpreting results, it is important to keep in mind the distinction between what a visitor actually hears, monitored results, and modeled results. What a visitor hears depends on the sound sources and meteorological conditions as well as the visitor's hearing ability at the time of audition. Monitored results also depend on sound sources and meteorological conditions, however those at the time of monitoring may not be the same as those that existed during the visitor's experience. Further, a visitor's hearing is more sensitive in areas with low sound levels than in areas with high sound levels. Monitoring systems do not account for this change in sensitivity. Modeled results are based on principles that describe how acoustic waves propagate and how humans perceive sound. They are also based on simplified representations of sound sources and propagation paths. The accuracy of modeled results depends on the detail of model inputs. For example, because the OSV sound sources in this modeling work are based on averaged data for each vehicle type, those with the highest and lowest sound pressure levels are not represented. So even though a visitor may be able to just hear a vehicle with an above average sound level, the model will indicate that the vehicle could not be heard.

4.1. Sample L_{Amax} Contour Maps

In order to compute a time audible contour (see Section 4.2), INM first computes a maximum A-weighted sound pressure level (L_{Amax}) as shown in Figure 23 and Figure 24. For maximum A-weighted sound pressure level contours, each color represents a different 10 dB(A) range. The legend indicates what percentage of park area each range covers. The maximum A-weighted sound pressure levels do not include ambient levels nor do they account for the threshold of hearing. The contour in Figure 23 illustrates the sound level due to a group of five four-stroke snowmobiles traveling in a group along all modeled segments in Yellowstone. Because the contours show the maximum level, additional groups of the same type of snowmobiles will not increase the contour levels[a]. Figure 24 illustrates the sound level due to a Bombardier snow coach traveling along all modeled segments in Yellowstone. The contours of the Bombardier cover a larger park area than the group of five four-stroke snowmobiles (compare for example 13 percent versus 10 percent for the 10 to < 20 dB range). This is due partly because of a higher sound pressure level near the source and partly due to less attenuation due to ground effects. (See Figure 35.) Maximum A-weighted sound pressure level contours were not calculated

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[a] INM computes each operation independently and assumes that there is no overlap.

explicitly for the six modeling alternatives, however, contours were calculated for preliminary modeling scenarios and are shown in Appendix G.

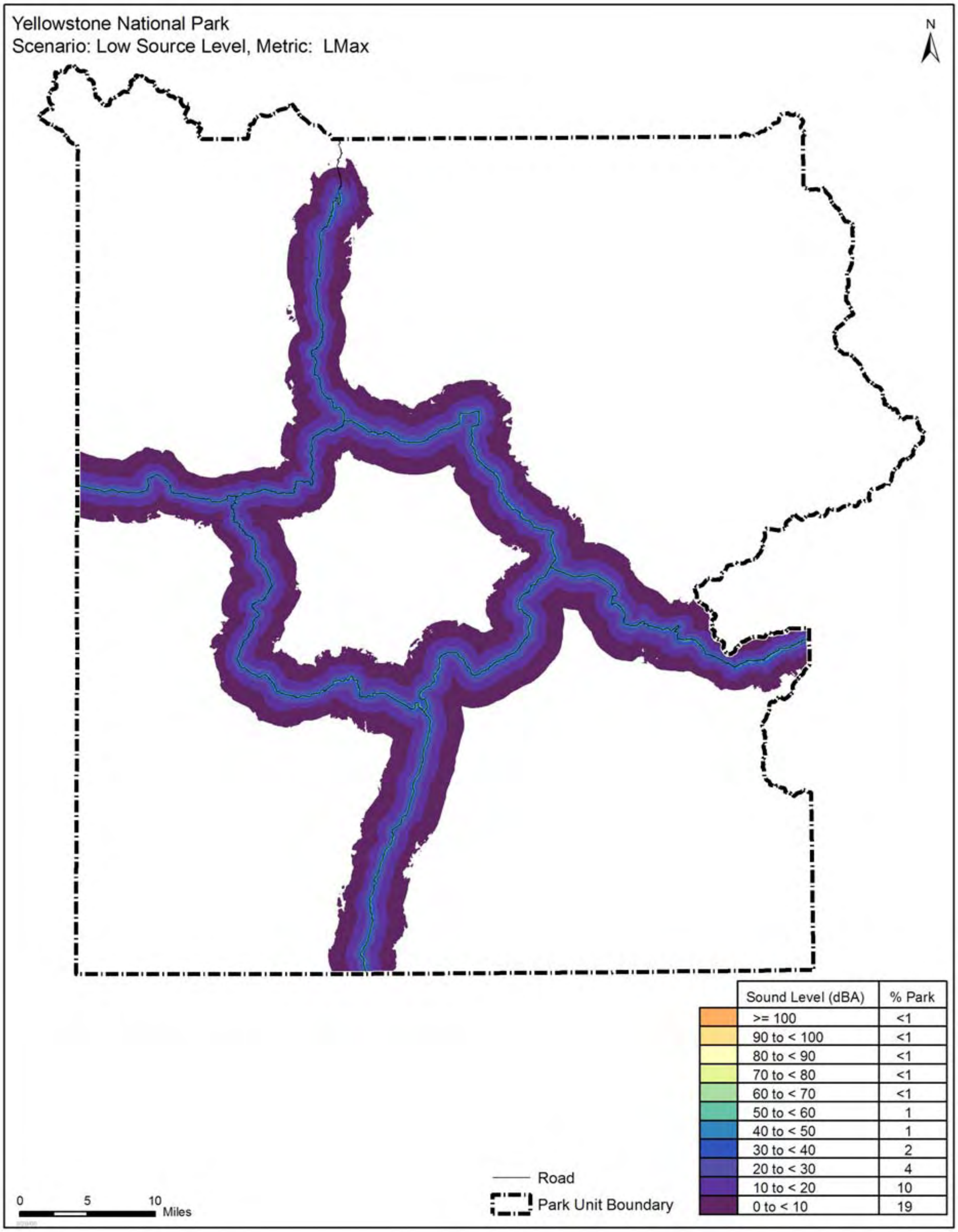


Figure 23: Low sound source level – Five four-stroke snowmobiles operating in a group.

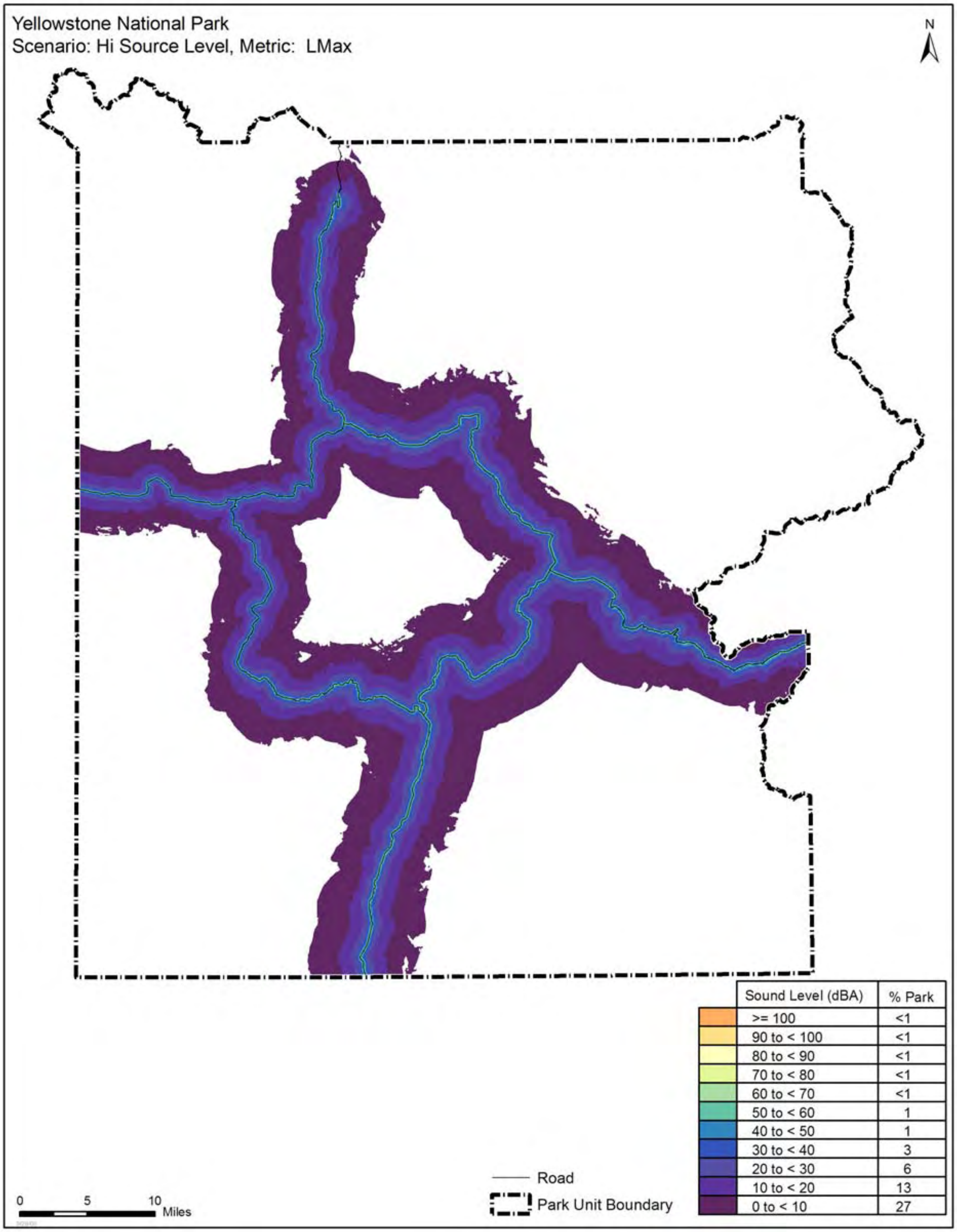
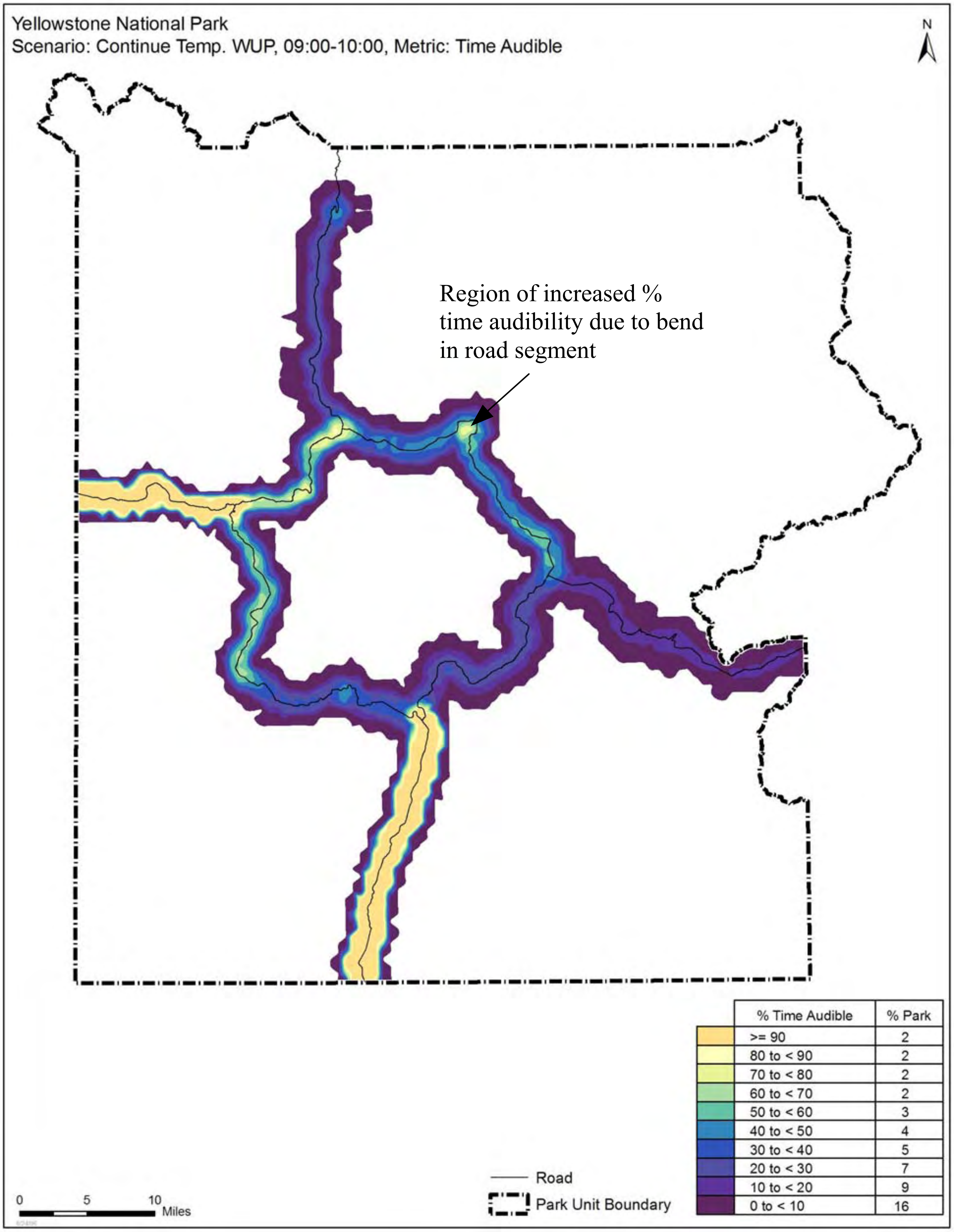


Figure 24: High source level – One Bombardier snow coach.

4.2. Percent Time Audible Contour Maps

The resultant INM percent time audible contour maps are shown in Appendix A. Sample percent time audible contours for Yellowstone are shown in Figure 25, Figure 26, and Figure 27 for Alternative 1A. Each color in the contour represents a different level of audibility. For example, the maroon contour indicates the area of the park that has audible events that occur not more than 10% of the time. In order to demonstrate the impact of peak and off-peak hours, contours presented in Figure 25 to Figure 27 and in Appendix E are for 1-hour time periods. Daily results are tabulated in Table 36 and Table 37 for Yellowstone and Table 38 and Table 39 for Grand Teton.

Based on the contours presented here, and in Appendix A, several general observations can be made about the modeling alternatives. 1) Events are generally audible within a relatively narrow corridor around the road segments. These corridors are typically between 3.5 and 5 miles wide. 2) Bends in the road segments increase the percent time audible in the area due to an increase in the exposure time as the vehicles traverse the curved region, see for example Figure 25. 3) The percent time audible reaches 100% near road segments with high numbers of hourly operations. For example, Alternative 1A has increased vehicle operations between 09:00 and 10:00 along the south entrance and west entrance roads due to visitors entering the park, resulting in 100% audibility along these roads during this hour. 4) When 100% audibility is reached the contour forms a plateau extending about 0.5 to 1.5 miles on either side of the road and then sharply drops to no audibility over a short distance. See for example the south entrance road in Figure 25. 5) Group size provides a potentially important tradeoff mechanism between park area and audibility. For example, in some areas of the park it may be desirable to increase the amount of time between successive OSV group events. This could be done in areas in which the concept of noise free intervals is important. By increasing group size, the noise free interval would effectively increase. The tradeoff is of course by increasing group size, the sound level associated with the group would increase and therefore the park area with "any audibility" would increase. Conversely, for areas of the park where 100% audibility has been reached, it may be beneficial to reduce group size. This would decrease the park area with "any audibility" but would not increase the percent time audible in the area nearest the corridor since it would already be at 100%. Further illustration of this tradeoff can be found in Appendix A.C.2.



Region of increased % time audibility due to bend in road segment

Figure 25: % time audible contour in Yellowstone for Alternative 1A, 09:00 to 10:00

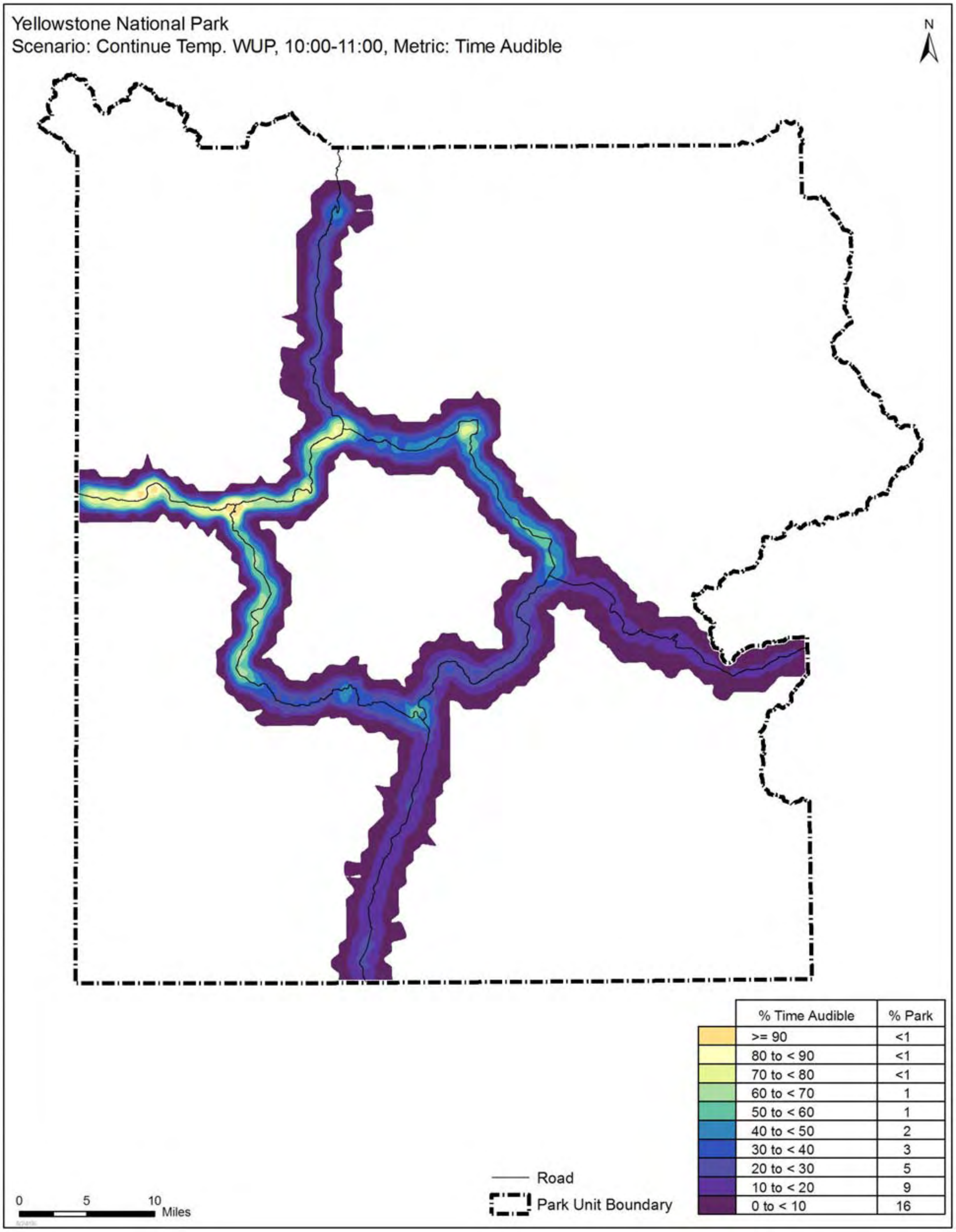


Figure 26: % time audible contour in Yellowstone for Alternative 1A, 10:00 to 11:00

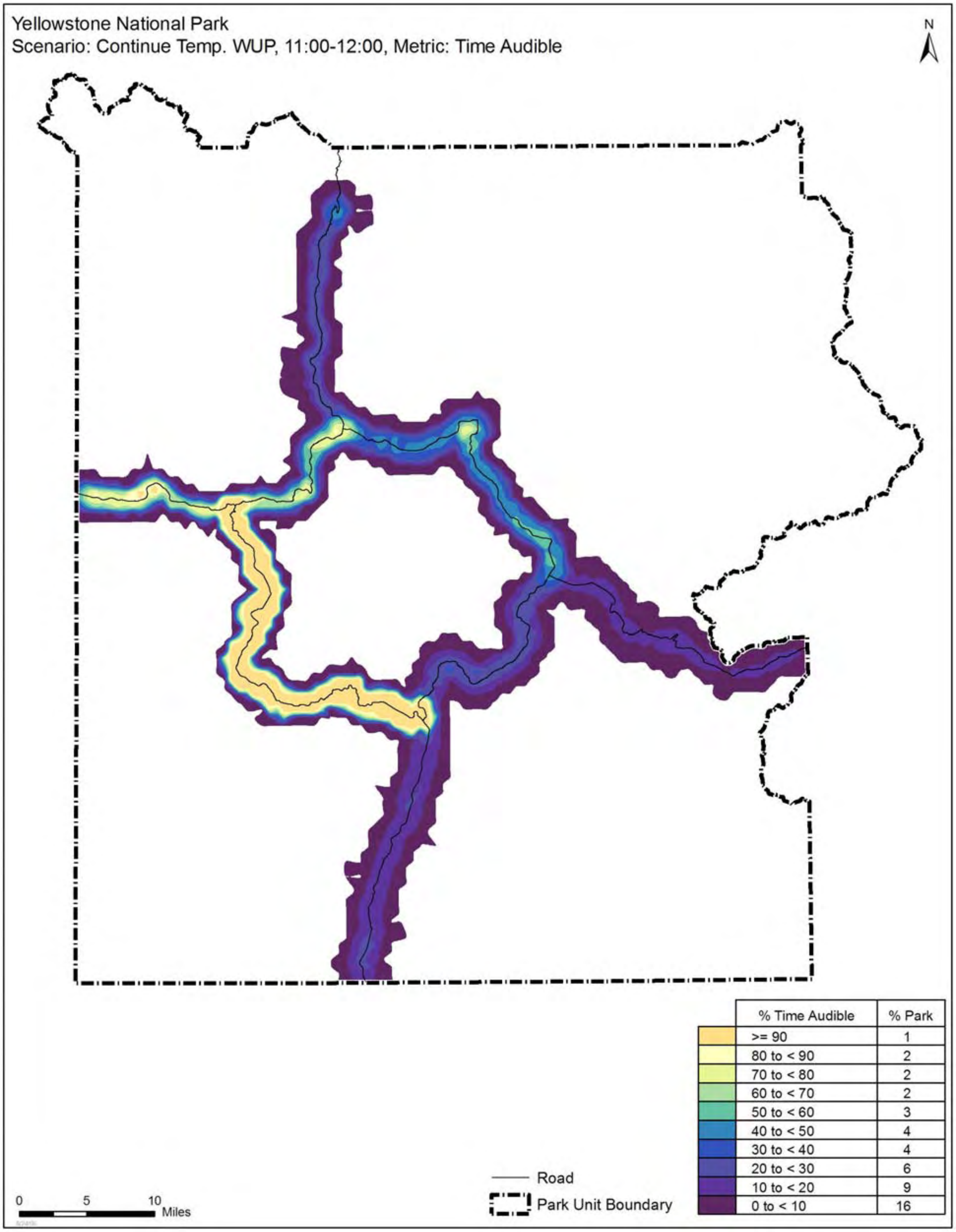


Figure 27: % time audible contour in Yellowstone for Alternative 1A, 11:00 to 12:00

4.3. Distributions based on Time Above A-weighted Level (TALA)

TALA was also calculated for sound levels starting at 0 dB(A) and increasing by 5 dB(A) until the level was not exceeded at any point during the given hour of operation. TALA was calculated for several locations that the Parks indicated were "points of interest". These locations are shown in Figure 28 and Figure 29 for Yellowstone and Grand Teton respectively.

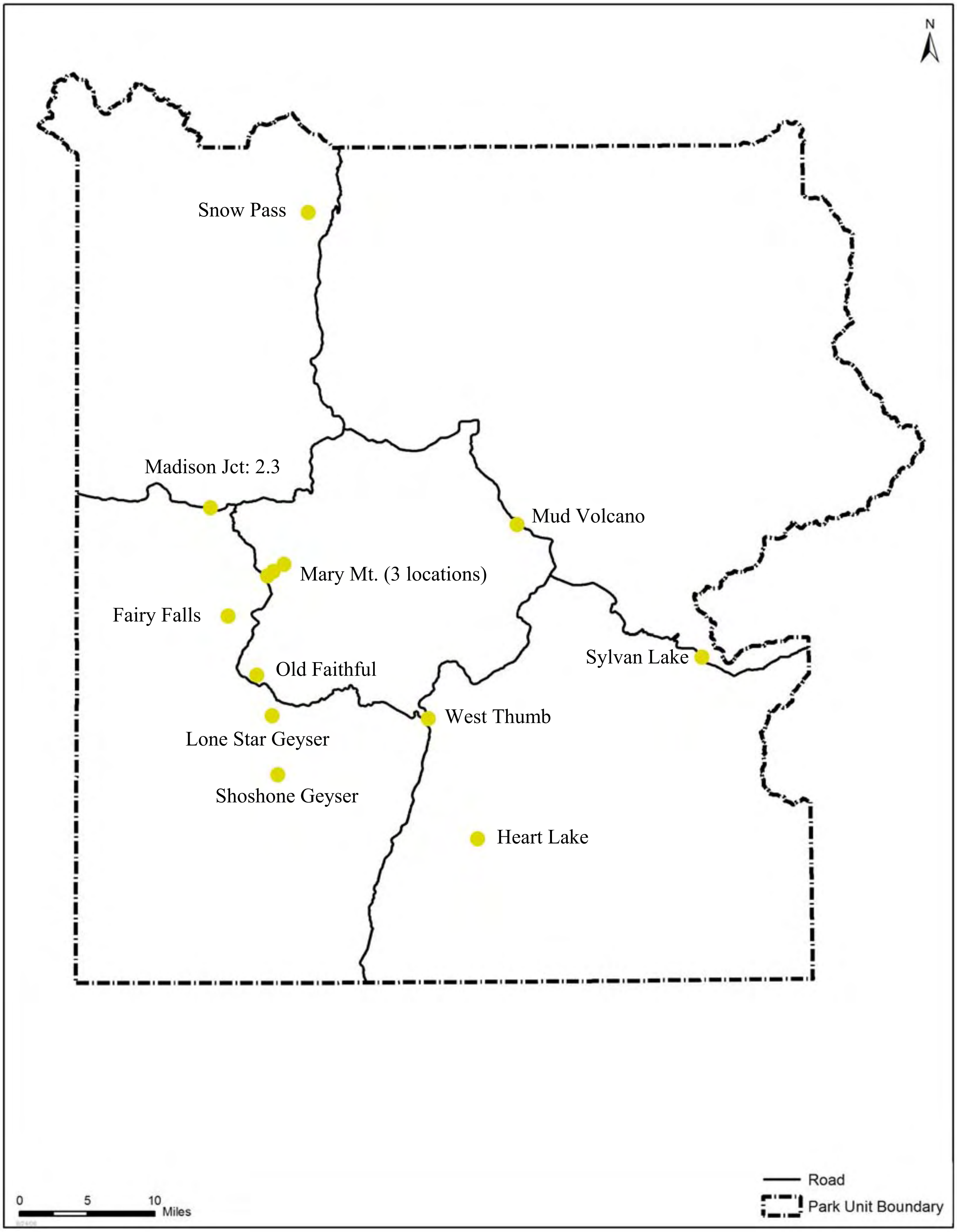


Figure 28: Location points in Yellowstone

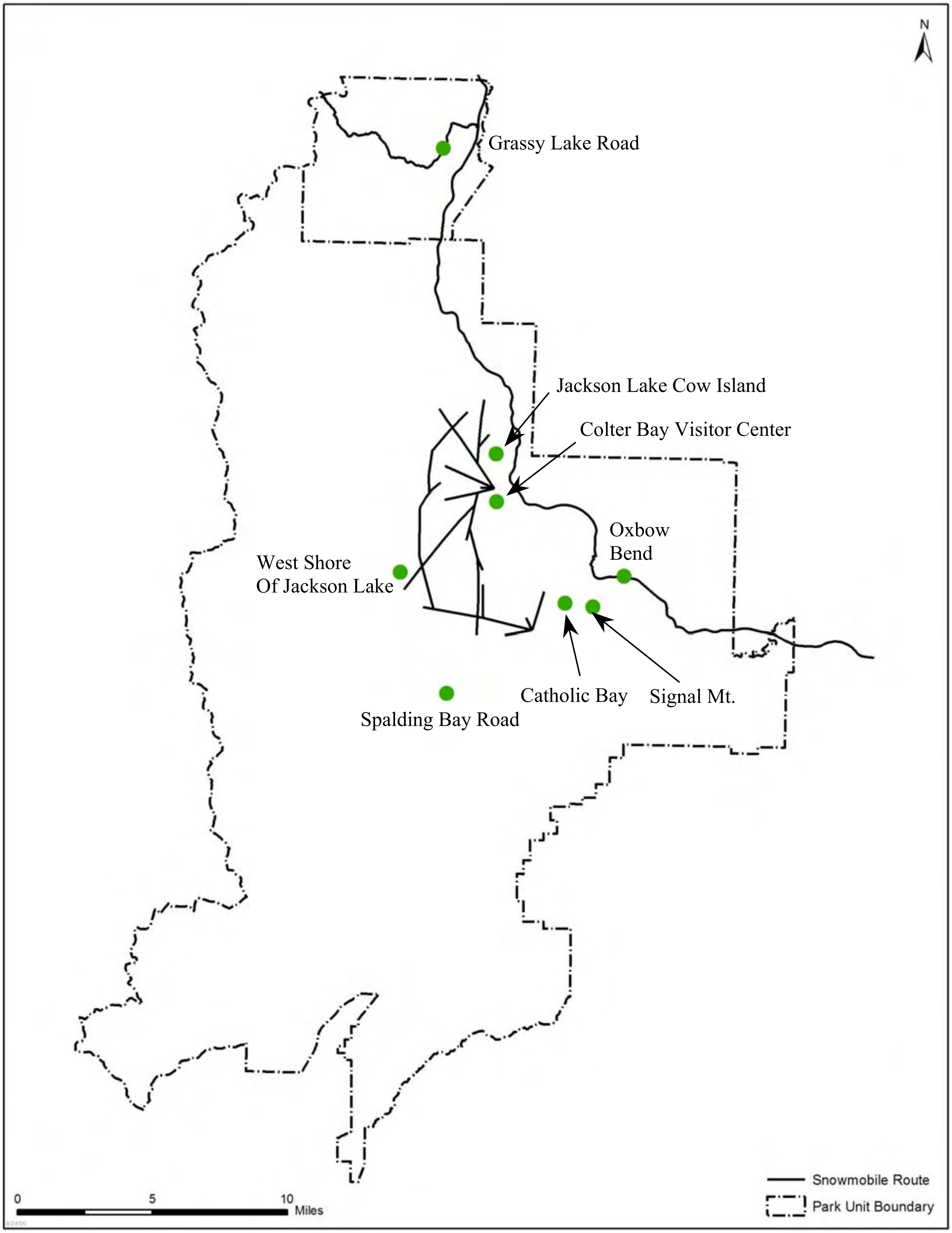


Figure 29: Location points in Grand Teton

Since TALA is a cumulative distribution, it always has the highest percentages at the lowest levels. This can be seen for the location point "Madison Junction: 2.3" in Figure 30 for Alternative 1A from 9:00 to 10:00 AM. It is sometimes instructive to show the time that the sound level is *between* two levels. This is equivalent to the difference between corresponding TALAs as given by,

$$\Delta TALA_{i-j} = TALA_i - TALA_j,$$

where i is the A-weighted sound pressure level for the lower end of the range and j is the A-weighted sound pressure level for the upper end of the range. These results will be referred to as ΔTALA. The distribution for ΔTALA for location point "Madison Junction: 2.3" is shown in Figure 31 for Alternative 1A from 9:00 to 10:00 AM. Note that in this case the lowest levels do not have the highest times. This is because 100% of the time has been allocated within the bands from 20 to 50 dB(A). Allocating additional time to other ranges would result in a time greater than one-hour for this one-hour interval.

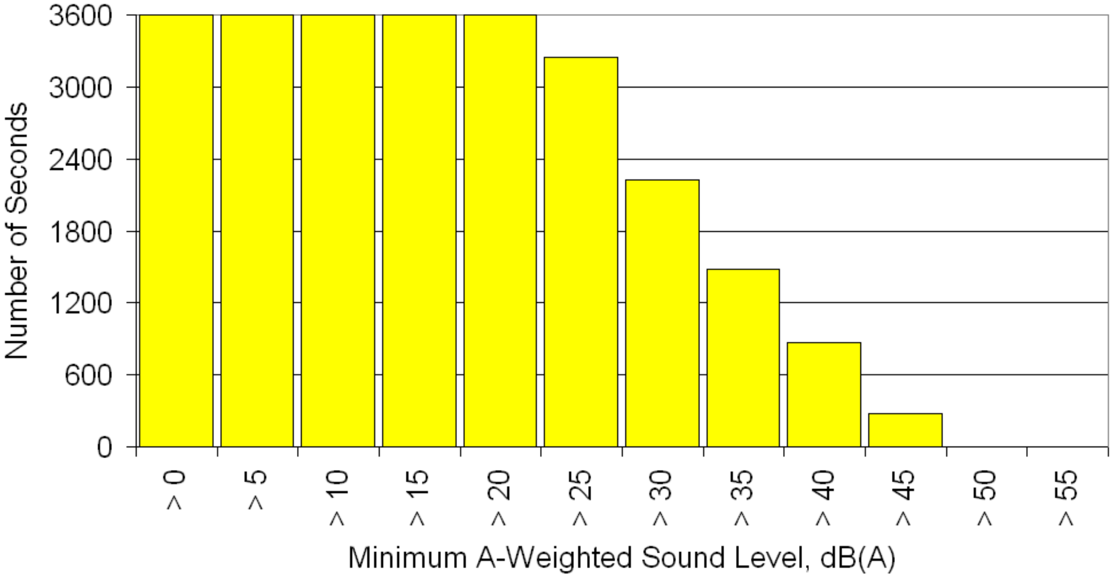


Figure 30: TALA at location point "Madison Junction: 2.3" location for Alternative 1A during the 9:00 to 10:00 hour

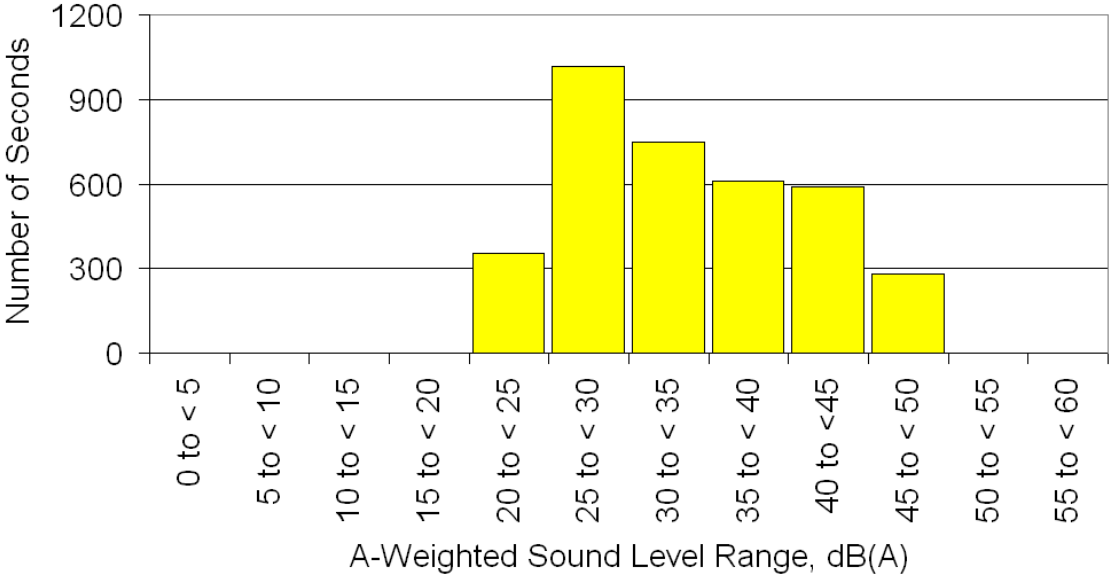


Figure 31: ΔTALA at location point "Madison Junction: 2.3" location for Alternative 1A during the 9:00 to 10:00 hour

Sample results for ΔTALA are shown in Table 12 for Alternative 1A during the 10:00 to 11:00 AM. Each row contains the results for a different location point. Each column is a 5 dB(A) range. The entry in the table indicates the number of seconds for the 1 hour period that the sound was within the specified 5 dB(A) range. For this modeling alternative / hour, Location points "Heart Lake" and "Shoshone Geyser" had no sound levels greater than 0 dB(A), while "Madison Junction: 2.3" had the highest sound levels. These results are typical since "Heart Lake" and "Shoshone Geyser" are far from the travel corridor while "Madison Junction: 2.3" is adjacent to the corridor. Results for all alternatives and hours are included in Appendix F. In many cases the indicated sound levels are below ambient for a given location. This however does not indicate that there are no audible events. Audibility generally depends on a single component having a sufficient signal-to-noise ratio[a] (SNR). That is, audibility can occur even when the overall level is below the ambient[26].

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[a] where the signal level is determined by the source and the noise level is determined by the ambient and auditory system noise

Table 12: ΔTALA, in seconds, at Locations in Yellowstone, Alternative 1A, 10:00 to 11:00

Number of seconds in dB Range	0 to < 5	5 to < 10	10 to < 15	15 to < 20	20 to < 25	25 to < 30	30 to < 35	35 to < 40	40 to <45	45 to < 50	50 to < 55	55 to < 60
Fairy Falls	166	32	0	0	0	0	0	0	0	0	0	0
Heart Lake	0	0	0	0	0	0	0	0	0	0	0	0
Lone Star Geyser	310	288	126	4	0	0	0	0	0	0	0	0
Madison Jct. 2.3	774	810	569	414	313	223	169	133	133	61	0	0
Mary Mt. 4000'	842	576	317	79	0	0	0	0	0	0	0	0
Mary Mt. 8000'	515	90	0	0	0	0	0	0	0	0	0	0
Mary Mt. Trailhead	806	500	346	274	270	119	4	0	0	0	0	0
Mud Volcano	641	464	356	288	230	176	47	0	0	0	0	0
Old Faithful	1253	778	580	306	7	0	0	0	0	0	0	0
Shoshone Geyser	0	0	0	0	0	0	0	0	0	0	0	0
Snow Pass	108	0	0	0	0	0	0	0	0	0	0	0
Sylvan Lake	180	137	104	68	50	36	25	22	14	14	11	0
West Thumb	745	569	407	288	184	86	36	0	0	0	0	0

When ΔTALA is analyzed hourly, the pattern is strongly affected by the number of operations near the location point. Overall, peaks in the hourly distributions correspond to hours that have peak operations on nearby road segments, thus peaks in the hourly distributions are consistent with high percent time audible results found in the contours, see for example Figure 25 to Figure 26.

Table 13: Hourly ΔTALA, in seconds for a given sound level range in dB(A). The location is Madison Junction: 2.3. The alternative is 1A.

Hour of Operation	0 to < 5	5 to < 10	10 to < 15	15 to < 20	20 to < 25	25 to < 30	30 to < 35	35 to < 40	40 to <45	45 to < 50	50 to < 55	55 to < 60
08:00 to 09:00	774	810	569	414	313	223	169	133	133	61	0	0
09:00 to 10:00	0	0	0	0	353	1019	749	608	590	281	0	0
10:00 to 11:00	774	810	569	414	313	223	169	133	133	61	0	0
11:00 to 12:00	760	824	763	220	313	223	169	133	133	61	0	0
12:00 to 13:00	760	824	763	220	313	223	169	133	133	61	0	0
13:00 to 14:00	760	824	763	220	313	223	169	133	133	61	0	0
14:00 to 15:00	774	810	569	414	313	223	169	133	133	61	0	0
15:00 to 16:00	0	0	0	0	353	1019	749	608	590	281	0	0

4.4. Ranking Modeling Scenarios

To summarize the results, the modeling alternatives were rank-ordered based on the percent of the park affected by 0 and 50% time audible for Yellowstone and by 0% time audible for Grand Teton[a]. The rank orders for any non-zero percent time audible, i.e. at least one audible event, are shown for Yellowstone in Figure 32 and for Grand Teton in Figure 34. From this point on, this will be referred to as "any audibility". The rank orders for greater than 50 percent time audible are shown for Yellowstone in Figure 33. The park percentages are obtained from the contour

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[a] Grand Teton did not have Alternatives with audible events 50% of the time so that ranking was not done for Grand Teton. Lower % time audible levels were examined, but the only significant effect was that for higher % time audible, the Current Conditions had the lowest rank due to its small number of operations.

plots in Appendix E by reading off the value in the "% Park" column of the map contours for the desired "% Time Audible".

4.4.1. Yellowstone Ranking

The graph in Figure 32 shows the percent of Yellowstone, which has "any audibility" during the entire 8-hour day. (The park area affected by a given percent time audible range for the entire day was determined by averaging the park area affected by a given percent time audible range for all hours.) In order to understand the rankings, it is constructive to consider some of the significant factors for each alternative. It can be seen that Alternative 3 has the lowest park area affected for "any audibility". This is quite reasonable, since this alternative included the closure of most road segments. Alternative 2 also has a relatively low audibility due to the exclusion of snowmobiles and the use of only BAT snowcoaches. Alternative 6 included the closure of the outer eastern portion of the east entrance road[a] and additionally included plowing of the west side of the park to allow wheeled vehicles rather than OSVs. (Wheeled vehicles have lower sound levels than do OSVs so audibility is reduced.) Alternatives 1B and 1D have lower audibility than 1A for the most part because in 1B and 1D the east entrance is closed, but for 1A it is open. Additionally, Alternative 1A included groups as large as 17 vehicles, the added vehicles increased the source level and thus the audible distance. Alternatives 5 and 4 both had the east entrance open, similar to Alternative 1A, however, some of their groups were smaller, 5 per group, resulting in lower source levels for some pass-by events, thus shortening the distance. The Current Condition did not have a BAT restriction on snowcoaches. This means that the vehicles with the highest sound levels of all modeled vehicles were included. Finally, the Historical Condition had the highest audibility because it includes the use of all road segments with no closures and it includes both BAT and non-BAT snowmobiles and snowcoaches.

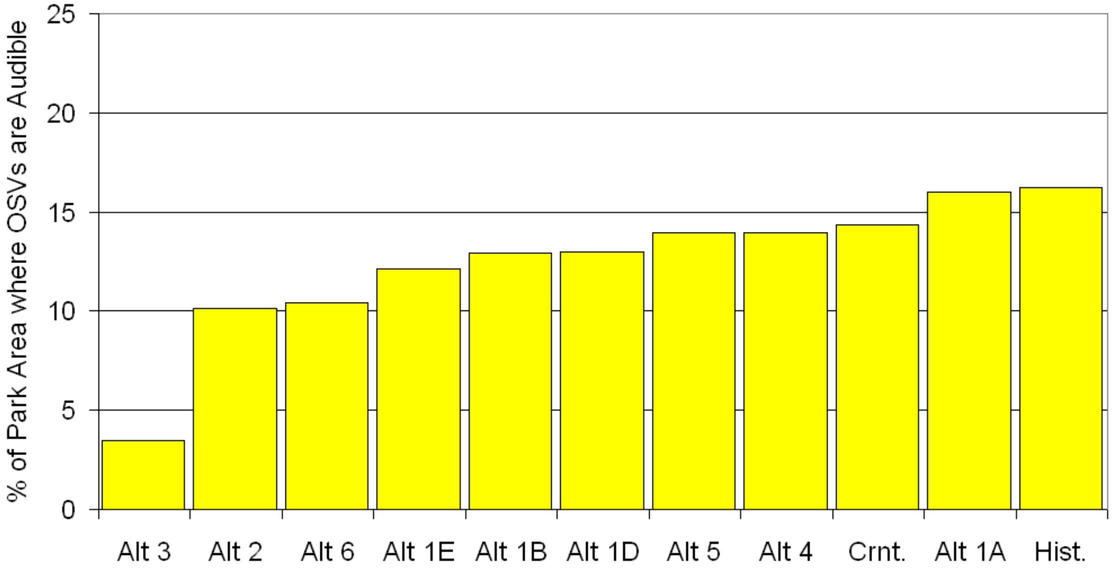

Figure 32: Percent of Yellowstone with any level of OSV audibility

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[a] The road segment from Fishing Bridge to Lake Butte should include some vehicle operations, but these were not provided by the Parks. Audibility will not increase significantly due to a small number of operations along this short road segment. Therefore this alternative will not be remodeled for the time being.

Whereas the case for "any audibility" represents the case where even a single event is heard and thus is strongly affected by source level and road segments open, the case for 50% audibility also includes a sensitivity to the number of operations that are audible. In Figure, the most significant effect of considering the 50% audibility case is that those alternatives with increased operations, namely Alternative 4 and the Historical Condition affect significantly larger park areas, while the audibility of the Current Condition, which has relatively low numbers of operations, moves down relative to the "any audibility" case. Overall, considering the case for both "any audibility" and the case for 50% audibility all modeling alternatives affect smaller park areas than does the Historical Condition for Yellowstone.

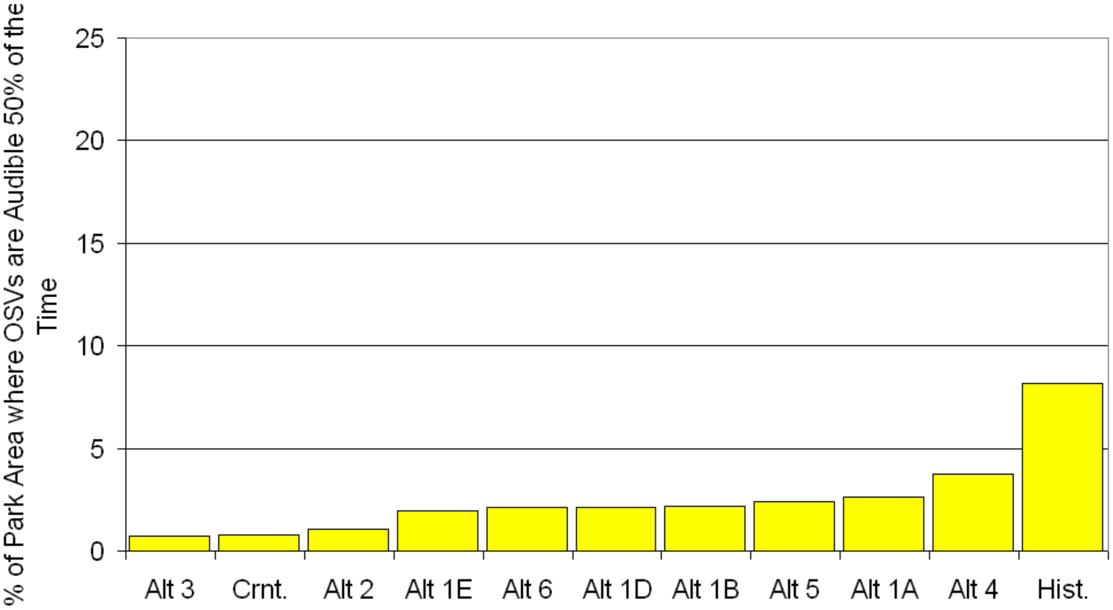

Figure 33: Percent of Yellowstone with 50% OSV audibility

4.4.2. Grand Teton Ranking

Figure 34 shows the percent of Grand Teton, which has "any audibility" over the entire 8-hour day. As with Yellowstone, a quick summary of significant factors is constructive. Because many of the alternatives in Grand Teton involved closing portions of the travel area (either the Grassy Lake road, the CDST, or Jackson Lake), the areas open to snowmobile use are a significant factor. Alternative 2 did not allow any snowmobile use in Grand Teton, thus it is not considered in this analysis. Alternative 3 had only the Grassy Lake road open to use so it is reasonable that it has the smallest park area affected. Both the Current Condition and Alternative 6 do not model travel along the CDST[a]. This is a long road, and its exclusion significantly reduces the park area affected by audible events. The four alternatives with highest audibility included use on all three travel areas in Grand Teton (Grassy Lake Road, The CDST, and Jackson Lake). Of the four, the Historical Condition has the lowest audibility because it was modeled using two-stroke snowmobiles. Although two-strokes have higher source levels according to the spectral data available (see Figure 43 and Figure 44 in Appendix C.1), they have more acoustical energy in the higher frequencies, thus their sound levels attenuate more quickly

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[a] For Alternative 6, travel along the CDST is prohibited. For the Current Condition, travel is very close to zero.

through the atmosphere. Alternatives 1 and 5 had very similar operations to the Historical Condition, but having four-stroke snowmobiles, they affected a slightly larger area than did the Historical Condition. Finally Alternative 4 had the highest audibility due in part to the inclusion of larger group sizes, 11 per group and therefore higher sound source levels, along the CDST.

The percent TAUD was generally below 20%. Because of these lower percentages, an analysis of 50% time audible was not conducted for Grand Teton.

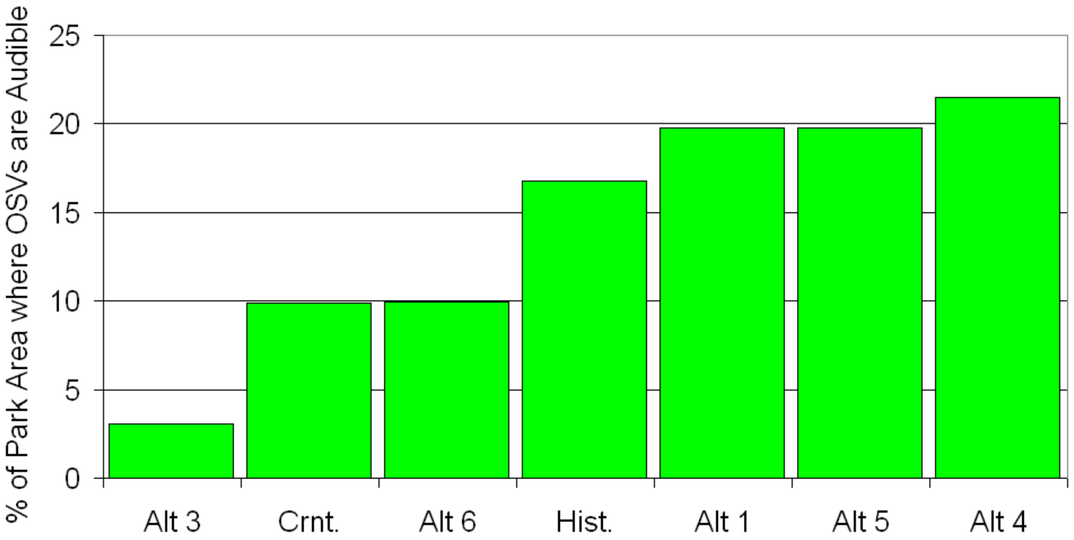

Figure 34: Percent of Grand Teton with any level of OSV audibility

5. Conclusions and Recommendations

A modified version of the FAA's INM Version 6.2 was developed to model the sound from OSVs in Yellowstone and Grand Teton National Parks. Modifications to the INM include new spectral classes and modified Noise-Power-Distance curves (Noise-Speed-Distance curves) for two- and four-stroke snowmobiles and three types of snowcoaches. Snowmobiles were modeled as operating in groups by combining the levels of all vehicles in the group into a single source (see Section 3.2.3 and Appendix A.C.2). In addition, the ground-to-ground propagation in INM was updated to be more representative of propagation over snow-covered terrain using the basic acoustic theory in the FHWA's TNM (see Appendix A).

The parks have been organized into two primary acoustic zones, open and forested, with natural ambient backgrounds provided by NPS for each acoustic zone. An additional zone, human development, has also been defined but has not yet been assigned its own unique ambient sound level (see discussion in Section 3.1.4). OSV paths were modeled along Yellowstone and Grand Teton roadways and on Jackson Lake in Grand Teton. Six NPS-designed modeling alternatives as well as current and historical conditions were studied. Each modeling alternative was evaluated for an 8-hour day with temperature, relative humidity, and snow cover representative of an average day during the winter season in the parks. In order to account for increased usage during peak hours, the 8-hour day was divided into 1-hour intervals and vehicle operations were assigned based on scheduling provided by the National Park Service. Results include contours for each alternative showing percent time audible (%TAUD) as well as tabulated time in seconds above specified A-weighted levels (TALA).

Percent time audible (%TAUD) contours and time in seconds above A-weighted level (TALA) were calculated for the modeling alternatives, as well as for current and historical conditions. The percent time audible contours had highest levels near the OSV travel corridors. Increases in operations increased the highest percent time audible up to a maximum of 100%. Increases in group size and the inclusion of snowcoaches that do not meet Best Available Technology (BAT) specifications increased the park area with "any audibility". Although not intuitive, inclusion of snowmobiles that do not meet BAT specifications did not increase the park area with "any audibility". Although these results were initially thought to be erroneous, further investigation indicated them to be correct and to be a result of the spectra associated with BAT and non-BAT snowmobiles. Specifically, the sound levels from non-BAT snowmobiles attenuated faster with increasing distance than the sound levels from BAT snowmobiles, which had greater sound energy at low frequencies. However, non-BAT snowmobile sound levels near the travel corridor were higher than BAT snowmobiles. Similar trends were found from the results of the TALA calculations.

The following additional work is recommended:

- Collect additional source data.
    - Include a greater range of vehicles and speeds to better represent the Park's OSV fleet. Include a greater range of vehicles and speeds to better represent the Park's OSV fleet. This should include any vehicles that make up a significant portion of the operations to be modeled, especially if no vehicles with similar acoustic characteristics have already been included.

    - Include a greater number of repetitions to provide more statistical confidence in the mean levels.
- Run controlled operations for validation, e.g. measure L_{Amax} for a single snowmobile at several locations simultaneously.
- Run modeling alternatives for cold and warm days and humid and dry days to determine sensitivity to weather extremes.
- Run alternatives for different types of snow cover, e.g., freshly fallen snow versus ice. This will require further modeling of ground effects.
- Use park fleet distributions to weight source data for each vehicle model when estimating the mean level for each source type. For example if there are 200 Snowbuster snowcoaches and 100 Bombardier snowcoaches in the park fleet, then the Snowbusters could be counted twice and the Bombardiers could be counted once when averaging source levels.
- Conduct surveys to determine visitor responses to alternatives that can be modeled. Averaged response ratings could be correlated to acoustic metrics such as percent time audible. This would provide an understanding of what metric levels are acceptable to park visitors.

It is understood that these tasks represent a large investment of several groups' time and resources. Further discussion needs to be conducted in order to prioritize these and to determine which items are actionable.