Scientific Assessment of Yellowstone National Park Winter Use March 2011

Prepared in support of the Yellowstone National Park Winter Use Plan / Environmental Impact Statement

Executive Summary

The purpose of this Science Advisory Team report is to summarize available scientific information in five topics related to the effects of snowmobile and snowcoach (oversnow vehicle (OSV)) use at Yellowstone National Park (YNP), and identify key findings for assessing the potential effects of OSV use, and propose future research to help address questions that cannot be resolved at present. These are some of the findings from this assessment.

Air Quality

- Air pollution related to winter OSVs at the park has primarily been problematic at congested locations such as the entrance stations, rest areas, thermal feature parking lots, and at Old Faithful. Measurements have shown that pollutant concentrations drop off rapidly with distance from the road and that air quality generally improves to near regional concentrations overnight (Ray, 2008; Sive, 2003; Zhou, 2010).

- The air quality condition for CO and $PM_{2.5}$ attributable to OSV traffic is currently well below the federal air quality standards at the congested areas near the west entrance and Old Faithful. Air quality conditions along most of the road segments are expected to be similar to the Old Faithful concentrations. At distances beyond 300-500 m from the roads, concentrations of CO, $PM_{2.5}$, and organics would be expected to approach background concentrations.

- NO_2 concentrations have been measured at concentrations at 20-80% of the standard by continuous monitors and for short periods at concentrations above 0.1 ppm. The NO_2 may be of more concern than CO or $PM_{2.5}$ at this point. 4-stroke engines and diesel engines have higher NOx emissions than 2-stroke snowmobiles.

- Winter activity by snowmobiles and snowcoaches contributes a greater amount of carbon monoxide than summer traffic, due to higher emissions from OSVs than cars and atmospheric conditions that inhibit the dispersal of emissions. Emission contributions from the current mix of BAT snowmobiles and unregulated snowcoaches is about equal. Even lower emission levels from modified production snowmobiles has been demonstrated in the Clean Snowmobile Challenge. Cleaner emitting snowcoaches than the present vehicles being used in the park have been demonstrated by the Bombardier snowcoaches outfitted with modern engines with pollutant controls and catalytic converters. A BAT for snowcoaches should be possible and would lead to a reduction in emissions.

- Spatial distribution studies indicate that the highest concentrations of air toxics, CO, and $PM_{2.5}$ are at congestion points and that concentrations drop rapidly with distance from the road. There are indications from the monitoring data that CO and $PM_{2.5}$is transported into the park from West Yellowstone during evening and night time hours when there is no OSV traffic on park roads. This probably occurs during the day also when winds are from the west. The West Yellowstone city center monitoring station records much higher CO and $PM_{2.5}$ concentrations during the day and concentrations persist late into the night. When winds blow towards the park entrance area, CO and $PM_{2.5}$ are observed at night even though there is no traffic on the entrance road.

- Personal exposure studies of air toxics have generally not found concentrations near the OSHA standards. The positive pressure ventilation system to the kiosks does a good job of maintaining clear air when the window is opened only briefly. If excessive idling is avoided and the entrance kiosks and the ventilation systems are working correctly, park employee exposure to air pollutants is below occupational standards.

- OSV management changes have been effective in reducing ambient air pollutants at the West Entrance and Old Faithful. The reduction in CO and $PM_{2.5}$ concentrations is due to lower numbers of OSVs, cleaner emissions from the BAT requirement, and changes in gate procedures that reduce the number of OSVs that are at the entrance.

- Some air toxics and hydrocarbons are being deposited near the road, but concentrations in the melt water are small. Some increased ammonium was observed in the snowpack close to the roads when 2-stroke snowmobiles were dominate, but those concentrations have decreased. Nitrate concentrations in the snow are low. Deposition from OSV emissions appears to drop off rapidly from the road edge and to be minor for distances of more than 300 m.

- Snowcoach emissions are a substantial part of the total. A BAT requirement that would limit the number of high emitted snowcoaches would have a positive effect on air quality along the roads and at congestion points. Administrative use of OSVs have become a larger percentage of traffic as the number of snowmobiles entering the park have decreased. The current administrative contribution to emissions and air quality is about 10%.

- The fate of OSV-specific pollutants within Yellowstone National Park have not been fully characterized, but we can infer from the available data that most potential ecosystem effects from OSV are negligible.

- No effect of OSV-emitted CO is expected on wildlife or vegetation at the atmospheric levels recorded in Yellowstone National Park (less than 3 ppm; Ray, 2010). While wildlife chronic exposure to CO has not been evaluated, we can infer from laboratory studies on animals and humans that the lowest effect levels require ambient concentrations to be much higher.

- Based on general knowledge and understanding of nitrogen sources and effects in the Western United States, additional inputs of nitrogen (as NO_3^- or NH_4^+) from OSV could be important to assess. The nitrogen emissions of OSV should be considered in the context of the background deposition levels.

- Buffered snow as is found in Yellowstone National Park would likely not affect soil acid status and that any potential OSV effects on chemical composition of soils would be imperceptible in part due to the geothermal and fire regimes within Yellowstone. The natural patterns of disturbance (such as fire, grazing and drought) likely mask any changes in soil nitrogen status from total (not just OSV) atmospheric deposition. Because the groomed snow road overlays the main summer road, soil health issues from compaction or erosion are not expected at Yellowstone National Park as a result of OSV use.

- Biota have adapted to specific hydrogeochemical conditions, some of which would be considered toxic or impaired anywhere else. Given these conditions it is unlikely that current OSV emissions would have a distinguishable effect.

- Generally, likely sinks for VOC in snow would be VOC in spring runoff and potentially some soil infiltration. Snowmelt data from 2003-2004 indicated VOC concentrations were low and did not exceed EPA standards for surface water and well below levels that would adversely impact aquatic systems.

Acoustic Resources

- Available community noise standards were not established to preserve the quality and character of acoustical environments, so the noise levels they specify will rarely be relevant to NPS resource management. However, the L_{Aeq} – or the average, A-weighted sound level metric used in many of these standards may be useful, because it has been the subject of so much research and is used to characterize many noise sources. The audibility of noise has been central to all previous NPS assessments of noise impacts. Audibility data can be used modify L_{Aeq} – or the average, A-weighted sound level to make these numbers easier to interpret, by averaging the noise level over the time when the noise is audible. Used in tandem, these two metrics can concisely represent the temporal extent of noise, as well average audible noise level.
- A measure of peak noise level was used in previous Yellowstone winter use environmental assessments; peak noise level metrics. The significance of this kind of peak exposure will be easier to assess if the metric provides an indication of the duration of these levels of exposure. For example and L_1 metric indicates that noise exceeds this level 1% of the time.
- An L_{Aeq} – or the average, A-weighted sound level of 35 dB appears in several standards addressing the quality of indoor spaces where good listening conditions are important. Application of ANSI S12.9-4 standards to OSV noise in Yellowstone suggests noise exposure should be below 35 dB, predicting that 4% of park visitors would be highly annoyed by noise exposure at this level. Several experts in the survey specified 35 dB as being pertinent to park management. Given the community noise context for these standards, NPS may find it appropriate to utilize this criterion when evaluating noise exposures in developed areas and travel corridors in the park.
- Two noise models are available that can evaluate the spatial extent of audible OSV noise in the park. They differ in some features, but are believed to yield similar results. Results from previous modeling efforts understated the spatial and temporal extent of audible OSV noise. Interpretation of future modeling results should be mindful of this

discrepancy. Research aimed at understanding the causes of this discrepancy could help improve future models and enhance their interpretation.

Wildlife

- Available evidence, including accident records from Yellowstone and studies of cause-specific mortality in other parks, suggests collisions with OSVs are not a significant source of mortality for wildlife of Yellowstone National Park.

- For species that have been studied extensively, ecological processes, and not OSV use, are dominant influences on wildlife vital rates and rates of increase. Recreational use of OSVs in Yellowstone increased from <5,000 oversnow vehicles entering the park in the 1960s to approximately 76,000 in the 1990s per year, then declined to about 25,000 oversnow vehicles per year in recent years. Visitors are now required to travel in groups, with commercial guides, and the resultant increase in group sizes has further reduced frequencies of disturbance. Two-cycle snowmobile engines have been replaced by quieter 4-stroke engines, and travel speeds have been reduced, reducing the intensity of disturbances that occur. Notwithstanding the magnitude of these changes, existing evidence does not suggest associated changes in vital rates or abundances of key wildlife species. Such factors as weather, predators, and plant succession, and not winter recreation, are clearly responsible for most variation in vital rates and abundance of elk and bison. Wolf numbers increased rapidly following reintroduction of the species in 1996, and trends in trumpeter swan numbers parallel broader regional trends.

- Collectively, studies conducted to date suggest effects of OSV on individual animals have not had measurable detrimental effects. Any behavioral or physiological reaction to disturbance associated with OSV use qualifies as an effect on an individual animal. However, studies of ungulate physiology suggest habituation to predictable disturbances like those associated with OSV use in Yellowstone. Observations of bison, elk, trumpeter swans, and bald eagles, which evince awareness of passing OSVs but typically are not displaced, do not suggest substantial energetic costs. Elk and bison near roadways do not appear to exhibit elevated levels of stress hormones attributable to OSV traffic. Effects of OSV use on the dynamics of intensively studied species clearly are subsidiary to effects of ecological processes, hence effects on individuals are either very slight or affect small proportions of populations.

- Current evidence does not support the notion that winter groomed roads contributed to population increases of bison, or are preferentially used by bison. However, road grooming may facilitate bison movements from the interior of the park to the northern range. An adaptive management experiment could help elucidate effects of road grooming on movements of bison through Gibbon Canyon, between the Central and Northern Ranges.

- Current practices used to manage OSV use in Yellowstone have likely reduced disturbance associated with motorized winter use and access. Individual animals have been shown to respond least, both behaviorally and physiologically, to non-threatening and predictable patterns of human recreation. Humans on foot and on skis, for example, generally elicit stronger behavioral responses from ungulates than do motor vehicles on roads. Disturbances to individual animals could increase if changes in winter recreation patterns lead to more prolonged, closer, or intense interactions between people and animals, particularly if such interactions are less predictable.

- Uncertainties that may be addressed through scientific investigation.
  - Recently developed GPS telemetry technology, which permits nearly continuous monitoring of animal movements, could be used to improve understanding of cumulative effects of winter use on wildlife habitat selection, rates of movement, time budgets, and levels of activity.
  - Observational data often provide limited support for cause-and-effect inference. Spatial patterns in distribution or abundance, for example, could result from carryover effects of summer use or from characteristics of roadways rather than OSV use. Integrating experimental manipulations of OSV use could dramatically strengthen inferences drawn from studies of wildlife distribution, abundance, and activity.
  - If studies of animal movement suggest avoidance of OSV travel routes, mapping forage utilization could provide insights about effects of OSV use on availability of forage for ungulates and implications of variable use for plant communities.
  - Existing Geographical Information System (GIS) themes describing park vegetation, topography, soundscapes, viewsheds, and wildlife distributions could be used to estimate proportions of biogeographic zones and wildlife populations that are exposed to disturbances associated with OSV use. Such information could alleviate concern for some species and populations and help focus future investigations where implications for conservation are greatest.
  - For some species, limited knowledge of distribution and abundance hamper assessments of winter recreation. Indices of abundance, probabilities of occupancy, or detection rates estimated from sign surveys, camera stations, or auditory surveys could permit cost-effective, geographically extensive assessments of distribution or relative abundance.

Social Science

- In terms of direct impacts from OSVs, a large body of literature addresses the role of noise in evaluation of visitor experience in recreational settings, applying either a psychological approach, acoustical approach, or a combination approach. Winter use plans at Yellowstone have adopted the acoustical approach, which has the advantage of relying on a specific objectively measured sonic environment. Yet, numerous studies indicate the importance of subjective qualities in the evaluation of sounds by visitors. Context, expectations, visual cues, foreground tasks, and trip motives are some of the factors that have been shown to affect evaluation of sounds as noise.

- Studies conducted in YNP corroborate the importance of natural sounds on visitor experience, and for the most part indicate that visitors have been satisfied with their soundscape experience, both before and after the managed-use era. Although studies have found that the importance of the soundscape sensory experience to Yellowstone's value, to visitors' experiences, and to their support for measures to reduce motorized noise depended on primary travel mode. Other studies indicated that visitors understood the tradeoff between the sounds of the vehicles they used to access the park and the natural quiet they desired to experience. Studies consistently report low support for closing the park's roads to all OSVs, regardless of primary travel mode.

- While studies generally report low effects from OSV noise on visitor experience, especially during the managed-use era, additional research could provide information on more specific elements that factor into subjective evaluation of OSV noise at YNP. Specifically, a dose-response study in the field would help social scientists and the park understand the level of noise exposure and effects in a typical winter. Objective measures from noise monitoring results would be correlated with visitors' evaluations of sounds and analyzed by context, expectations, and other factors that may affect experiences. A similar study in a laboratory could help determine the relationships between audibility or annoyance and the number of OSVs, effects of snowcoach BAT, and impact of OSVs (visual and noise) on hearing and appreciation of natural sounds or landscapes. The restricted generalizability of laboratory experiments to field conditions is compensated for by the greater control in lab settings over the variables being tested. Together, both laboratory and field studies would contribute to a more complete understanding of the impacts of OSV use on winter use experiences. In some cases, as the Muir Woods soundscape studies indicate , it is possible to adapt laboratory methods and controls for use in field settings. Finally, noise monitoring could be modeled in GIS to create a "noise exposure surface" that could be compared to a study of visitor flows through YNP. This type of analysis can yield an objective measure of visitor noise exposure across the landscape, which could then be compared to results from the dose-response studies.

- With respect to potential impacts from other aspects of OSVs on visitor experience, visible haze and odors from exhaust emissions, impacts on wildlife viewing opportunities, and safety were reviewed. When two-stroke machines dominated snowmobile use in the park, the emissions they produced had a negative impact on the experiences of some visitors, yet issues of haze or odor from exhaust fumes or other sources were not mentioned spontaneously by respondents in studies conducted in the managed-use era. While studies have not been specifically designed to assess visitor evaluations of objective measures of emissions (e.g., human dimensions of OSV emissions), national standards for air quality and emissions may serve as adequate proxies, given that visitors did not identify issues related to exhaust emissions when air quality considerations were being managed.

- Studies related to wildlife viewing have focused on visitor perceptions of bison viewing opportunities and bison activity. The opportunity to view bison was rated as important to most visitors, regardless of primary mode of transportation. At present levels of OSV use, visitors are likely to be satisfied with their opportunities to view bison in the park, although there may be some differences in how different groups appraise the nature of these interactions. Studies have not examined the degree to which opportunities to view other types of wildlife in the park factor into visitor evaluations of their winter experience.

- In addition, few studies have specifically examined safety impacts from changes in OSV policies. Given that studies in other park units have indicated concerns over safety with increasing density of recreational use, as well as a correlation between user density and the feeling of being crowded, a similar study in YNP could be warranted if access is increased or group size and/or spacing between groups is managed.

- In addition to direct impacts from OSVs, managed winter use also can result in conflicts that affect visitor experience. In the context of winter use at YNP, noise-based conflicts and identity-based conflicts were identified as potentially most salient. Noise-based conflicts have not been explicitly studied at YNP, although they could be addressed as components of the broader noise studies suggested above. Similarly, information on identity-based conflicts between winter user groups in YNP has not been systematically collected. Researchers have noted that OSV management policies impact (or privilege) some users more than others. Better understanding the degree to which these differential impacts contribute to conflicts between user groups would help managers identify and address potential points of controversy. Further, additional studies that focus on visitor motives, the psychological benefits they seek, and norms of behavior as alternate ways to segment the public may help identify drivers of conflict that were previously overlooked.

- Changes in management policies not only can privilege some experiences or users, they also can displace others. Visitor displacement has been documented in many recreation locations, and is one reason aggregate levels of satisfaction in visitor studies can remain high, even in the face of dramatic changes in the nature of a setting. The review of controversy over management actions noted that studies from the unmanaged-use and managed-use eras appear to suggest that most park visitors are satisfied with whatever current conditions and management actions exist at the time, but that inclusion in these studies of non-visitors or displaced visitors could have brought a different perspective. Similarly, studies of economic impacts document the substitution from snowmobile to snowcoach use in response to changes in management policies and also suggest some snowmobile activity may be displaced to other nearby public lands. The little research on displacement that has been conducted relative to winter use at YNP has been inconclusive, and no systematic studies have been conducted in the managed-use era. However, there is value in understanding displacement of visitors or locals due to implemented management actions such as OSV or BAT requirements, as well as the consequences of displacement and potential substitutes (both in areas outside YNP or to different activities within YNP). This could be examined systematically at local, regional and national levels through interviews with key informants, community surveys, or even small-scale experiments within an adaptive management framework.

- In addition to current and displaced visitors, the impacts of winter use management at YNP also can affect people living in regions around the park. Potential impacts include economic impacts to those who depend on winter tourism for their livelihoods, as well as impacts to individual lifestyles and communities. While researchers have argued that successful management of this region needs to acknowledge and incorporate local populations' knowledge and attitudes about the area, management strategies, and economic impacts, few regional studies have been conducted. While some original research on the economic impacts and valuation of winter use in YNP has been conducted (Duffield and Neher 2006; National Park Service 2005) additional research on these topics could help inform assessment of regional impacts from management actions.

Table of Contents

Acronyms

ANSI	American National Standards Institute
BAT	best available technology
CO	carbon monoxide
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
GC	glucocorticoid
GIS	geographic information system
GYE	Greater Yellowstone Ecosystem
HC	hydrocarbon
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NO_2	nitrogen dioxide
NOx	nitrogen oxide
NPS	National Park Service
OSHA	Occupational Safety and Health Administration
OSV	oversnow vehicle
SO_2	sulfur dioxide
SWE	snow water equivalent
USGS	United States Geological Survey
VOC	volatile organic compound
YNP	Yellowstone National Park

1. Introduction

In November 2009, the Superintendent of Yellowstone National Park (YNP) established a Science Advisory Team to support the Yellowstone National Park Winter Use Plan / Environmental Impact Statement. The Science Advisory Team charter specified the following primary goals:

- Enhance the accountability and integrity of YNP scientific assessments of impacts from winter use activities on park natural resources.
- Provide additional scientific interpretation of existing research to support analysis in new National Environmental Policy Act (NEPA) documents and long-term winter use management plans.
- Provide scientific recommendations for the experimental designs and adaptive management methodologies for monitoring changes in impacts to park resources, values, and visitor experience resulting from managed winter use.
- Integrate and interpret future scientific results to provide regular updates on the best available assessment of the consequences of winter use for park resources, values, and visitor experience. Ensure science is accurately represented and integrated into decision making. The Science Advisory Team will provide independent peer review of scientific information to meet Department of the Interior and National Park Service (NPS) mandates under the Information Quality Act.

The Science Advisory Team (SAT) members are Dr. Kurt Fristrup, NPS Natural Sounds Program Center; Dr. Kurt Jenkins, USGS Forest and Rangeland Ecosystem Center; Dr. Kirsten Leong, NPS Biological Resource Management Division; Dr. Bruce Peacock, NPS Biological Resource Management Division; Dr. John Ray, NPS Air Resources Division; and Dr. Glen Sargeant, U.S. Geological Survey (USGS) Northern Prairie Wildlife Research Center.

The scientific assessment of Yellowstone National Park winter use was directed by D. Mary Foley and prepared with input from members of the SAT assisted by the Rocky Mountain Cooperative Ecosystem Studies Unit, and faculty and students from the University of Montana and the University of Maine. The SAT was informed by facilitated workshops with natural resource and social science experts in February 2010 and air quality experts in May 2010 (see Appendix A for the names of attending scientists), and a modified Delphi process with acoustics and soundscape experts in July 2010. The SAT utilized their professional judgment to identify important issues in a series of facilitated conference calls throughout winter-summer 2010.

2. Air Quality

2.1 General Background on Air Quality

Before considering the research, monitoring, and modeling related to winter air quality at Yellowstone National Park, we first will review the relevant air quality standards, rules, regulations, and policies (NPS, 2010).

NPS Organic Act

The National Park Service Organic Act of 1916 states that the NPS: [S]hall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified … by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to *conserve* the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them *unimpaired* for the enjoyment of future generations (16 U.S.C. §1; italics added). Congress reaffirmed this mandate in 1978 when it directed the following: The authorization of activities shall be construed and the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress (Act amending the Act of October2, 1968 [commonly called Redwood Act], March 27,1978, P.L. 95–250, 92 Stat. 163, 16 USC §§1a–1, 79a–q). The no-impairment mandate of the Organic Act is one of many legal requirements managers must consider and comply with when authorizing activities in parks. In some cases, requirements of air quality or other environmental laws and regulations might prohibit certain impacts on natural resources or values, irrespective of whether NPS managers would consider the impacts to rise to the level of "impairment." In other cases, impacts technically allowed by law might be prohibited in a park because they would be considered by NPS managers to be an impairment of park resources. Generally, the most stringent test should be applied prior to approving an activity. In addition to avoiding impairment, NPS managers must always seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values. However, the laws do give NPS the management discretion to allow certain impacts to park resources and values when necessary and appropriate to fulfill the purposes of a park, so long as the impact does not constitute impairment of the affected resources and values.

2.1.1 EPA Standards

The Clean Air Act (CAA) and the Environmental Protection Agency's (EPA) Regulations established the National Ambient Air Quality Standards (NAAQS) to protect the public health and welfare from air pollution (US EPA, 2008). The NAAQS describe thresholds (see Table 2-1) for monitored air pollutant concentrations of "criteria pollutants" of interest in Yellowstone: nitrogen dioxide (NO_2); sulfur dioxide (SO_2); carbon monoxide (CO); ozone (O_3); and particulate matter ($PM_{2.5}$). Threshold concentrations for these pollutants designed to protect human health are called "primary standards" and are intended to protect human health rather than natural resources (Table 2-1). EPA has also established "secondary" NAAQS to protect public welfare, including ecosystems. However, in most cases the secondary NAAQS are identical to the primary NAAQS. EPA is currently reviewing and revising secondary NAAQS to provide appropriate protection to natural resources.

Table 2-1. Ambient air quality standards (AAQS) for carbon monoxide (CO), nitrogen dioxide (NO_2), and particulate matter less than 2.5 micrometers ($PM_{2.5}$). (ppm = Parts Per Million; $\mu g/m^3$ = Micrograms per cubic meter)

Standard	Pollutant	1-hr CO (ppm) [1]	8-hr CO (ppm) [1]
National AAQS	CO	**35**	**9**
Montana AAQS	CO	**23**	**9**
Wyoming AAQS	CO	**35**	**9**
National AAQS[4]	NO_2	**0.100**	**--**

Standard	Pollutant	24-hr $PM_{2.5}$ 98th percentile ($\mu g/m^3$) [2]
New NAAQS [3]	$PM_{2.5}$	**35**
Montana AAQS	$PM_{2.5}$	**35**
Wyoming AAQS	$PM_{2.5}$	**65**

1. Not to be exceeded more than once per year. Link to EPA NAAQS standards: http://www.epa.gov/air/criteria.html ; WY DEQ http://deq.state.wy.us/aqd/standards.asp ; MT DEQ http://www.deq.state.mt.us/AirMonitoring/citguide/appendixb.html
2. The 3-year average of the 98th percentile of 24-hour concentrations at each monitor within an area must not exceed 35 $\mu g/m^3$. The winter 98th percentile in the associated tables is given only to demonstrate the improvement between winter seasons. Comparison with the annual standard is not shown. For consistency, the 24-hour day is used to average the hourly $PM_{2.5}$.

3. Revised $PM_{2.5}$ standard by EPA Oct. 2006, down from 65 $\mu g/m^3$.

4. The revised NO2 standard is 100 parts per billion (ppb), calculated from the average of the 98th percentile of 1-hour daily maximum concentrations from three consecutive years.

Areas of the country that do not meet the NAAQS for any pollutant are designated as "nonattainment areas." In nonattainment areas, states must develop plans to reduce emissions and bring the area back into attainment of the NAAQS. There are stringent requirements for activities conducted by federal agencies in nonattainment and maintenance areas, to ensure that proposed pollution increases from new activities will not impede a state's ability to achieve the NAAQS in the future. Section 176 of the CAA states: No department, agency, or instrumentality of the Federal Government shall engage in, support in any way or provide financial assistance for, license or permit, or approve any activity which does not conform to an [State] implementation plan.

Clean Air Act and Amendments

NPS air resource management policy has been developed in conjunction the Organic Act and with requirements in the Clean Air Act (CAA) and the Environmental Protection Agency's (EPA) regulations. The level of protection afforded some park resources and values by the CAA may be the determining factor when deciding whether air quality impacts are acceptable. Air pollution sources within park boundaries, must, by law, comply with all federal, state, and local regulations to the same extent as other entities. The CAA established National Ambient Air Quality Standards (NAAQS) to protect the public health and welfare from air pollution. Parks located in areas that exceed the NAAQS (nonattainment areas) or whose resources are already being adversely affected by current ambient air quality levels require a greater degree of consideration and scrutiny when management actions are considered by NPS managers.

Prevention of Significant Deterioration (PSD)

The CAA also established the Prevention of Significant Deterioration (PSD) of Air Quality program to protect the air in relatively clean areas. One purpose of the PSD program is to protect public health and welfare, including natural resources, from adverse effects that might occur even though NAAQS are not violated. Another purpose is to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic or historic value (42 U.S.C. 7401 et seq.). The PSD program includes a classification approach for controlling air pollution. Class I areas are afforded the greatest degree of air quality protection. Very little deterioration of air quality is allowed in these areas. Class I areas include international parks, national wilderness areas and national memorial parks in excess of 5,000 acres, and national parks in excess of 6,000 acres that were in existence as of August 7, 1977, when the CAA was amended. Currently, there are 48 areas in the National Park System designated as Class I; Yellowstone National Park is a mandatory Class I area. NPS areas that are not designated Class I are Class II, and the CAA allows only moderate air quality deterioration in these areas. However, pollution increases causing a violation of any of the NAAQS are not permissible in Class I or Class II areas.

The PSD regulatory program generally consists of permitting and planning requirements to limit air quality deterioration and to prevent adverse impacts on Air Quality Related Values in Class I areas. The PSD program focuses primarily on large stationary sources of air pollution which would be located outside of park boundaries. However, source very near or in a park can have a disproportionate impact. Regardless of classification, for PSD permit review purposes into Class I or Class II areas, all parks enjoy the same level of Organic Act protection,

Vehicle emission standards

The EPA has set emission standards on cars, trucks, buses, and other on-road vehicles that has brought emissions of CO, PM, Pb, and VOCs down over time to relatively low levels. Off-road vehicles, such as snowmobiles or modified vehicles for over-snow use, were basically unregulated until the 2002. EPA has set hydrocarbons (HC) emissions standard for lighter on-road vehicles of 0.3 gm/mile that phases in to 100% of the new passenger vehicle fleet by 2013 (US EPA, 2008). Tier II rules for light-duty on-road vehicle emissions apply to most new cars and light-duty trucks. Table 2-2 has emission limits for late model cars and light trucks for on-road summer travel that can be compared to the winter OSV emissions. Most snow coaches fall into heavier duty vehicle categories than contained in Bins 1 through 11. Tier II limits are much lower than the measured emissions of OSVs at Yellowstone. Most snow coaches fall into the

Table 2-2. Tier 2 exhaust emission standards for light duty vehicles (US EPA, 1999)

	Standard	**Emission Limits at 50,000 miles**				
		NOx (g/mi)	**NMOG (g/mi)**	**CO (g/mi)**	**PM (g/mi)**	**HCHO (g/mi)**
Federal	Bin 1	-	-	-	-	-
	Bin 2	-	-	-	-	-
	Bin 3	-	-	-	-	-
	Bin 4	-	-	-	-	-
	Bin 5	0.05	0.075	3.4	-	0.015
	Bin 6	0.08	0.075	3.4	-	0.015
	Bin 7	0.11	0.075	3.4	-	0.015
	Bin 8	0.14	0.100 / 0.125[c]	3.4	-	0.015
	Bin 9[b]	0.2	0.075 / 0.140	3.4	-	0.015
	Bin 10[b]	0.4	0.125 / 0.160	3.4 / 4.4	-	0.015 / 0.018
	Bin 11[b]	0.6	0.195	5	-	0.022

Notes: **Web:** http://www.epa.gov/otaq/standards/light-duty/tier2stds.htm

Tests Covered: Federal Test Procedure (FTP), cold carbon monoxide, highway, and idle

Model Year: 2004+

a In lieu of intermediate useful life standards (50,000 miles) or to gain additional nitrogen oxides credit, manufacturers may optionally certify to the Tier 2 exhaust emission standards with a useful life of 150,000 miles.

b Bins 9-11 expire in 2006 for light-duty vehicles and light light-duty trucks and 2008 for heavy light-duty trucks and medium-duty passenger vehicles.

c Pollutants with two numbers have a separate certification standard (1st number) and in-use standard (2nd number).

OSHA Standards

OSHA sets workplace standards for multiple air pollutants including CO, NOx, and hydrocarbons (OSHA, http://www.osha.gov/SLTC/healthguidelines/index.html). These standards generally apply to employees and a common work period, usually taken as 8 hours. The employees most at risk are at the entrance stations, at warming hut areas, and park staff using snowmobiles. EPA has designated aromatic compounds (EPA, 1992; http://www.epa.gov/OMSWWW/toxics.htm) , such as benzene and toluene, as hazardous air pollutants (HAPS) from mobile sources. A table listing several organic and inorganic HAPS, for which measurements have been made in the park, is reproduced from Sive et al, 2003 in Table 2-3 below. Comparisons to these standards will be made in a later section.

Table 2-3. Comparison of occupational exposure standards for various air pollutants (Sive et al., 2003)

Compound	NIOSH REL (ppm)	NIOSH STEL (ppm)	OSHA PEL (ppm)	OSHA STEL (ppm)
CO	35	200	50	
Benzene	0.1	1	1	5
Toluene	100	150	100	150
Ethylbenzene	100	125	100	125
Xylenes	100	150	100	150
Styrene	-	-	100	-
1,2,4-Trimethylbenzene	25	-	-	-
1,3,5-Trimethylbenzene	25	-	-	-
n-Hexane	50	-	500	-
NO	-	-	25	-
NO_2	-	-	-	5

TWA = time weighted average (typically 8-hours)

STEL = Short Term Exposure Limit (typically 5 to 15 minutes)

PEL = OSHA permissible exposure limit as an 8-hour TWA

REL = NIOSH recommended exposure limit for an 8-hour TWA

2.1.2 Air Quality Standards in National Parks

The NPS does not set air quality standards, but does follow the federal and state standards. A technical guidance on assessing impacts to air quality (NPS, 2010) discusses multiple evaluation criteria. The impact levels for NEPA project review are related to the federal air quality standards in Table 2-4 (NPS-ARD, 2010) and should be applied consistently regardless of Class I or Class II area designation.

Table 2-4. Assessment table from Guidance Document on Air Quality Impacts to health.

Impact level	8-hr Ozone (ppm)	1-hr Carbon Monoxide (ppm)	8-hr Carbon Monoxide (ppm)	1-hr Sulfur Dioxide (ppm)	24-hr PM_{10} (μg/m^3)	24-hr $PM_{2.5}$ (μg/m^3)	1-hr Nitrogen Dioxide (ppm)
Negligible	0–0.040	0-0.2	0–0.2	0–0.001	0–11	0–5	0–0.001
Minor	0.041–0.037	0.2-17.5	0.3–4.4	0.002–0.034	12–77	6–17	0.002–0.049
Moderate	0.038–0.059	17.6-27.9	4.5–7.1	0.035–0.059	78–119	18–27	0.050–0.078
Major	0.060- 0.075	28.0-35.0	7.2 - 9.0	0.060- 0.075	120-150	28- 35	0.079-0.100

2.1.3 Air Emissions from Over Snow Vehicles

Snowmobiles and snowcoaches emit air pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HCs; a subset of which are volatile organic compounds (VOCs) and air toxics (benzene, toluene, xylenes etc)), and particulates ($PM_{2.5}$). All internal combustion engines produce theses emission products; the issue, especially two-stroke snowmobiles, has been the very high emission rates of CO and PM. The difference in emissions between 2-stroke and 4-stroke snowmobiles can be seen in the summary Table 2-5. CO is reduced by about 85% and HC by 98% while NOx increases by 15 times over the 2-stroke emissions. To illustrate that even the current Best Available Technology (BAT) snowmobiles are not clean emission vehicles, the same engines are used in some small cars and test a factor of 10 lower emissions (Bishop, 2010). Current BAT snowmobiles lack catalytic converters that could further reduce emissions. Snowcoaches demonstrate a similar relationship due to the snow resistance and track weight (see later discussion). A converted Bombardier snowcoach with a Suburban SUV truck engine and catalytic convert has lower emissions than the 4-stroke BAT snowmobile, but on average BAT snowmobiles and newer coaches had similar emissions on a per passenger basis when tested in 2006. Snowmobiles in the SAE Clean Snowmobile Challenge routinely achieve exhaust emissions much lower than the BAT limits (Meldrum, 2010). Diesel engines in snowcoaches have low CO emissions, but the PM2.5 and NOx emissions are much higher. The dynamometer tests are very hard to relate to measured emissions in field tests because several assumptions have to be made to convert from gm/kW-hr to gm/mile. A rough equivalence can be estimated from Table 2-5 by using the dynamometer tests and the field tests for BAT snowmobile engines. The emissions from 2011 model year snowmobiles are given in Table 2-6 for comparison. It is less clear that the dynamometer gives meaningful results for snowcoaches being operated under high load conditions in the snow. On-road vehicles typically get much lower emissions; Table 2-2 has the EPA Tier II standards where CO emissions are 3.4 gm/mi and NOx of 0.05 to 0.4 gm/mi.

Table 2-5. Summary of OSV emissions from various non-EPA tests

			g/mi	**g/mi**	**g/mi**	**g/mi**	
Reference	**Vehicle**	**Method, conditions**	**CO**	**HC**	**PM**	**NOx**	**NOx/CO ratio**
SwRI, 2002	2-stroke snowmobile	dynamometer (15-20 mph)	220	180	4.1	0.21	0.001
Bishop, 2009	2-stroke snowmobile	remote sensing, 1999	85	110	- -	- -	
SwRI, 2002, 2002	BAT snowmobile (15-20mph)	dynamometer	35.1	2.8	- -	2.9	0.082
Bishop, 2006	4-stroke BAT snowmobile	field study, tailpipe	37	4.5	- -	3.2	0.087
Bishop, 2009	4-stroke BAT snowmobile	remote sensing, 2005	27	3.2		3.2	
SwRI, 2002	4-stroke snowmobile	dynamometer (15-20 mph)	35	2.8	0.8	2.9	0.083
Bishop, 2006	4-stroke SM engines in cars (on road)	dynamometer	3.4	0.41	- -	0.4	0.118
Bishop, 2006	Snowcoaches Range	field study, tailpipe	5 - 600	1 - 34	- -	1 - 26	
Bishop, 2006	Snowcoaches mean	field study, tailpipe	230	6.7	- -	19	0.083
Bishop, 2006	Snowcoaches cleanest	field study, tailpipe	5	1	- -	1	0.083
SwRI, 2002	Ford van snowcoach	Chassis dynamometer (15-20 mph)	66.7	1.1	0.28	1.4	0.021
SwRI, 2002	snowcoach engine, gasoline	dynamometer, engine only	<5	<0.41	- -	<1.1	0.220
SwRI, 2002	Diesel snowcoach	dynamometer, engine only	<8	- -	0.12	49	6.130
Bishop, 2006	NPS diesel, Ford van	field study, tailpipe	7.2	- -	0.12	49	6.130
Bishop, 2006	NPS diesel bus	field study, tailpipe	6.6	- -	0.33	31	4.697

Reference	Vehicle	Method, conditions	gm/kW-hr CO	gm/kW-hr HC	CO % of BAT	HC % of BAT	
SwRI, 2002	Arctic cat	engine dynamometer	93.9	6.6	78.3	44.0	
SwRI, 2002	Polaris	dynamometer	103.9	5.6	86.6	37.3	
SwRI, 2002	Ski-Doo	dynamometer	92.9	4.7	77.4	31.3	
NPS	**BAT limits**	**dynamometer**	**120**	**15**	**- -**	**- -**	

2.1.4 Best Available Technology for Over Snow Vehicles

In November 2002, the U.S. Environmental Protection Agency promulgated nationwide regulations for snowmobile emissions (Federal Register, Volume 67, No. 217, Page 68242, November 8, 2002). By 2012, EPA will require that the corporate average carbon monoxide emissions not exceed 275 grams per kilowatt-hour and corporate average hydrocarbon emissions not exceed 75 grams per kilowatt-hour. The 2012 pollution level for each snowmobile engine family is determined through a formula that balances HC and CO emissions. According to the 2008 regulation, "The Phase 3 standard equation in essence requires nominal 50 percent reductions in CO and HC compared to uncontrolled levels, which are 150 g/kW-hr for HC and 400 g/kW-hr for CO. However, the equation is structured such that mixes of CO and HC reductions can be used. In conjunction with a straight HC limit of 75 g/kW-hr (ensuring at least 50 reduction in HC) and a corporate average CO standard that could not exceed 275 g/kW-hr (ensuring at least approximately 30 reduction in CO), the equation allows up to 70 percent reductions of HC and 30 percent reductions of CO, as long as the percentage reduction of both pollutants combined is at least 100 percent." (Federal Register, Volume 67, No. 217, page 35948).

Snowmobiles

The NPS air emission requirements (generally called best available technology "BAT") are considered to be requirements to enter and operate a snowmobile in Yellowstone National Park. NPS BAT requirements rely on the same EPA-established testing protocols contained in the EPA regulations, and on manufacturer certifications to EPA regarding the emissions produced by snowmobiles. However, NPS BAT requirements call for hydrocarbon emissions not to exceed 15 g/kW-hr and carbon monoxide emissions not to exceed 120 g/kW-hr. These are family emission limits (FEL) (that is, the manufactures may certify that different model snowmobiles using the same engine all will meet the emissions limits). When a snowmobile is certified by the NPS as meeting BAT requirements, certification is good for six years. (Federal Register, Vol. 74, No. 223, November 20, 2009, Page 60159). NPS BAT requirements have been in place since the 2004-2005 winter season.

Family emission limits are typically higher than actual tailpipe emissions because they take into account manufacturing variance, deterioration of the engine over time (the EPA regulations require that a machine meet the emission regulations for five years or 5,000 miles), and differences between models using the same engine. For example, for a 2011 Arctic Cat snowmobile, the FELs are 9 g/kW-hr for HC and 99 g/kW-hr for CO, while the certification data provided to EPA indicates actual emission for HC is 6.65 g/kW-hr and for CO, 74.71 g-kW-hr. BAT snowmobiles average 25 miles per gallon (Bishop et al 2010)

Typically, manufacturers have certified their snowmobiles with HC levels ranging from 8 to 15 g/kW-hr and CO levels ranging from 105 to 120. Although the NPS BAT requirements are more stringent than even the 2012 EPA regulations, the NPS believes EPA regulations are helping spur the development of improved snowmobile technology and reduced emissions nationwide. As manufacturers develop technologies to meet the 2012 requirements, the NPS is seeing model year 2011 snowmobiles that produce emissions well below NPS BAT requirements (Table 2-6). For example, CO FEL emission for a new engine model found in seven, 2011 models certified as BAT for use in Yellowstone is 90 g/kW-hr. Table 2-6 summarizes the standards and current FEL values for 2011 snowmobiles.

Table 2-6. Comparison of emission standards and snowmobile models to average 2-stroke snowmobile emissions (NPS, 2011)

Snowmobile	Air Emissions (g/kW-hr) FEL			
	Hydrocarbons	Carbon Monoxide	% HC reduction	% CO reduction
Average 2-Stroke (Non-BAT)	150	400	- -	- -
EPA Snowmobile Air Emission Requirements[1]	75	275	50	31
NPS BAT Requirements[2, 3]	15	120	90	70
Arctic Cat 2011	9	99	94	75
Bombardier 2011	8	90	95	78
Polaris 2011	15	120	90	70
Yamaha 2011	11	120	93	70
Bearcat 2011	9	99	94	75

[1] EPA Family Emissions Limits (FEL) for Snowmobiles are 75 for Hydrocarbons and 275 for Carbon Monoxide (2010 and 2011 model years). (See *Federal Register* Vol. 73, No. 123, Wednesday, June 25, 2008, page 35946)

[2] Hydrocarbons: certified by EPA to a Family Emissions Limit (FEL) of 15 g/kW-hr or less.

[3] Carbon Monoxide: certified by EPA to a Family Emissions Limit (FEL) of 120 g/kW-hr or less.

Snowcoaches

Snowcoaches are either wheeled vans or small busses converted to over-snow use or they are older Bombardiers built in the 1950s and 1960s specifically for over-snow travel. Snowcoaches may also include "snow-cats," tracked vehicles that are designed for over-snow travel. According to the 2009 Interim Winter Use Plan FONSI, snowcoaches are "Self-propelled, mass transit vehicles intended for travel on snow, with a curb weight of over 1,000 pounds (450 kg), driven by a track or tracks, steered by skis or tracks, and having a capacity of at least eight passengers. A snowcoach has a maximum size of 102 inches wide, plus tracks (not to exceed 110 inches wide with tracks); a maximum length of 35 feet; and a Gross Vehicle Weight Rating (GVWR) not to exceed 25,000 pounds."

There is no "manufacturer" of snowcoaches. Of the 78 coaches currently operating, approximately 20 different makes and models of vehicles (along with multiple years) are represented (see the report by the Volpe, 2010 or Bishop et al, 2006 for photographs and descriptions of a cross-section of current vehicles).

Wheeled vehicle performance may or may not be a good indicator of the air emission characteristics of the same vehicle as a snowcoach running on tracks due to the resistance from the snow surface and the need to operate the vehicles at or near full throttle for significant portions of their duty cycle to overcome that resistance (Bishop, 2006). In addition, track systems add considerable weight to the vehicle, and some vehicles are converted to four-wheel drive, which changes performance characteristics from those reported by the manufacturer. Modern vehicle design tends to emphasize smaller engines to reduce emissions and improve fuel economy. These vehicles may not have the power to move a tracked vehicle at a reasonable speed. Snowcoach fuel economy is low due to all these issues, with 2 to 4 mpg typical (Bishop et al 2010).

For a considerably longer period of time than snowmobiles, EPA has been promulgating regulations regarding wheeled vehicle emissions. Two recent EPA reports summarize the EPA's vehicle and engine compliance activities, which includes all types of cars and light trucks, heavy duty engines, and non-road equipment (2007 report is found at http://www.epa.gov/otaq/about/420r08011.pdf and the 2008 report (dated August 2010) is located at http://www.epa.gov/otaq/about/420r10022.pdf). EPA wheeled vehicle emission regulations are being implemented over the next several years for light-heavy to medium-heavy duty trucks and many "converted snowcoaches" are based on these vehicle classes. Although emission characteristics of a vehicle in a tracked, over-snow mode are not comparable to its performance on wheels, these technological changes should also result in lower emissions for snowcoaches. As these new vehicles become available, testing will be needed to determine actual over-snow performance.

The decision document for the 2008 Interim Winter Use Plan requires snowcoaches to meet air emission standards that were in effect when the vehicle was manufactured. However, operators were encouraged to replace or retrofit snowcoaches with models that meet higher emission standards, including those for EPA 2007 “engine configuration certified” diesel engines and Tier 2 requirements for gasoline engines.(NPS 2009a). The family emissions limits (FEL) approach for snowcoaches may not work if only the engines are tested and not the final over-snow version under actual conditions. Both the remote sensing and the direct emission measurements showed that load conditions on the snowcoaches are quite variable and lead to unpredicted engine performance as the loads exceed the expected conditions for the vehicles computer control.

2.1.5 Secondary pollutant formation (acidic deposition, ozone, etc.)

Potential for secondary pollutant formation

One study of winter air pollutants found secondary organic aerosol (SOA) formation to be a minor contribution to overall PM (Sive, Shively et al. 2003). Aerosol emissions from 2-stroke snowmobiles were suggested as the source of PM since diesel vehicles were a minor part of the vehicle mix and PM concentrations increased during the day in a pattern that followed increased hydrocarbon concentrations.

A combination of NOx and VOC, such those from mobile sources, provide the right mix so that in the presence of sunlight, ozone is formed in the lower atmosphere. This is the process that occurs in urban areas. Winter time formation of high ozone concentrations has been observed in Wyoming near gas development areas when the weather is cold, snow is on the ground, and the skies are clear (Pinto, J., 2009). Ozone is monitored at the water tower site north of Lake Village year-round (Ray, 2009). No high winter ozone concentrations have been observed and the ozone concentrations during winter have not changed in any way that relates to the winter traffic volume.

The water tower monitoring site near Lake Village also measures dry deposition of sulfate, nitrate, nitric acid, and sulfur dioxide. The nitrate compounds are formed from oxidation of gaseous NOx in the atmosphere. If OSVs contribute significant amounts of the above acidic deposition products, then winter concentrations should be higher than the Fall or Spring periods. Instead, spring and summer are the highest periods for nitrate and ammonium; winter is the lowest (Ray 2009; http://www.epa.gov/CASTNet/data.html). The CASTNet site at the water tank is more than 500 m from the road traveled by the OSV, so it may be too far away to be affected.

2.2 Studies Related to Resource Impacts from Over Snow Vehicles

This section addresses whether the presence and magnitude of some pollutants derived from over-snow vehicle (OSV) emissions may have detrimental effects to aquatic and terrestrial ecosystems. In some cases, limited data were available within Yellowstone National Park boundaries, so we discuss potential effects from research elsewhere. Further, recent improvements in snowmobile emissions and requirements that allow only limited numbers of commercially guided best available technology (BAT) snowmobiles within Yellowstone National Park were intended to improve air quality; few studies characterize presence of these pollutants both before and after implementation of this requirement. The objective of this review is to provide context for current OSV emission levels and their potential to affect Yellowstone National Park ecosystems.

2.2.1 Air Resources

Background

Vehicle emission effects on air quality are well known, but the effects on vegetation physiology, soil composition, runoff chemistry, surface water quality, and aquatic biota health are more difficult to characterize (Lovett et al. 2009). However, much of the research on vehicle emission and traffic effects was performed with on-road vehicles and may not be directly relevant to OSV use within Yellowstone National Park. In general, emissions from OSV and subsequent deposition are known to affect snowpack chemistry (Ingersoll, 1999). Runoff from snowmelt generally flows into local surface waters; studies at other sites have found species assemblages affected by acidification (Lepori et al. 2003) or toxicity (for example, Baldigo et al. 2009) resulting from compounds deposited in the snow.

Approach

This synthesis seeks to collate information on the scope and severity of potential air quality effects relevant to managing winter use within Yellowstone National Park. The approach used was to identify pollutants of interest based on typical components of vehicle exhaust (ammonia, for example) and their potential effects on ecosystem components (canopy or soil, for example). If sufficient data were available, we attempted to compare the level of current, local OSV emission deposition with that which would be expected to produce adverse effects. Because these effects are sometimes species or pollutant specific, winter environmental sampling is very limited, and because ecosystems are exposed to multiple stressors simultaneously, it was difficult to assess the overall consequences of OSV-derived air pollution with any precision. However, the existing literature does provide some guidance for which potential conditions may affect a similarly sensitive ecosystem, thus information included is not always representative of western, alpine forests in winter affected by OSV traffic. General information about air quality effects on ecosystems can be found in Lovett et al. 2009 and Fowler et al. 2009.

Due to the number of potential pollutants, effects, and approaches to measure them, the research discussed here has been categorized by its relevance to OSV use within Yellowstone National Park. Pollutants and effects measured:

- In winter within Yellowstone National Park are considered ***directly*** relevant.
- In the vicinity of Yellowstone National Park are ***regionally*** relevant
- In similar ecosystems or under similar use conditions are ***inferentially*** relevant.
- In general context of fossil fuel combustion and ecosystem health are ***generally*** relevant

In some cases, only general information is available, but any potential or lack of effects are inferred when possible.

The pollutants of ecological importance related to general fossil fuel combustion include carbon monoxide, hydrocarbons (including volatile organic compounds and polycyclic aromatic hydrocarbons), nitrogen oxides, ammonia, particulate matter, mercury, carbon dioxide and ozone.

2.2.2 Human Health

Generally, carbon monoxide (CO) is a human health concern near high traffic areas and enclosed spaces where carbon-based fuels are combusted. CO reduces delivery of oxygen to the body's tissues; Pollutants from two-stroke engines emit between 10 and 70 times more CO and between

45 and 250 times more HC than an automobile (US EPA 1996). The exposure levels for snowmobile users during travel in groups can be above acceptable health standards (Kato, 2001; Eriksson, 2003; Snook-Fussel, 1997), especially if following closely or in large groups.

Particulate Matter

As a component of OSV exhaust, particulate matter (PM) is a concern for air quality, but not necessarily for ecosystem health. Particulates affect lung function and cause respiratory problems. Most documented effects of PM have been in severely polluted industrial areas (Grantz et al. 2003). Atmospheric PM has been defined mainly by size fractions rather than in terms of chemical nature, structure, or source. While relevant for human health effects and visibility, size has little correlation with ecosystem effects. Instead, the chemical composition of PM drives ecosystem response (Grantz et al. 2003). Components of PM deposition are a mix of trace metals, organics, acid anions, and base cations. Potential effects of PM on ecosystems summarized from Guderian (1977) include accumulation of pollutants in plants, soil and surface water; changes in species diversity due to changes in nutrient availability or toxicity; and disruption of biogeochemical processes.

Direct evidence from a winter 2006-2007 (post-BAT) study in Yellowstone National Park (NPS, 2007), near Old Faithful, reported the maximum 24-hour average $PM_{2.5}$ concentration as 6.6 ug/m^3; this value was only 10% of the NAAQS standard of 35 ug/m^3. Much of the PM2.5 at Old Faithful occurs during hours when OSVs are not present which is consistent with non-mobile sources such as structure heating, wood or propane fired stoves, and broiler/kitchen operations being the sources. In general, potential negative effects from PM are likely to be subtle at sites that not severely polluted, although they may be additive to nitrogen deposition, acidification, and when combined with other atmospheric pollutants.

Volatile organic compounds

Volatile organic compounds (VOC) belong to a broad classification of hydrocarbons (HC), some of which are present in vehicle exhaust. Hydrocarbons include hazardous pollutants (i.e., benzene and formaldehyde) and can be toxic or increase the risk of cancer or other disease.

Whereas human health effects of chronic exposure to some VOC are well documented (see Kado et al. 2001, and http://www.epa.gov/iaq/voc2.html), it should be noted the presence of atmospheric VOC presents different risks than the presence of VOC indoors. A precursor to ozone formation under certain conditions and a major component of smog, VOC may have direct and indirect effects on ecosystems. Vehicles and off road equipment were two primary sources of VOC emissions for Park County, WY in 2005 (U. S. EPA, 2009). However, a study in 1999 estimated that 77% of annual HC emissions in Yellowstone National Park were directly attributable to snowmobile exhaust (Bishop et al. 2001). BAT was required for snowmobiles in 2004, one goal of which was to reduce HC emissions by 90% (Zhou et al. 2010). Substantial decreases in emissions of HC were verified in new BAT four-stroke snowmobiles compared with older two-stroke models (Bishop et al. 2009; Zhou et al. 2010). The magnitude of HC in snowcoach exhaust has been related to the vehicle fuel-injection technology, and the snow conditions on the road (Bishop et al. 2009). Limited data are available for snowpack, runoff, or stream VOC concentrations after 2004 (discussed in following sections), but prior to the BAT requirement, there were measurable VOCs in snowpack and spring runoff (Ingersoll, 1999; Arnold and Koel, 2006). The snowmelt study within the park conducted in 2003-2004 (just prior to BAT implementation) found elevated VOC concentrations at high OSV traffic sites compared with the control site, but all samples were below U.S. EPA water quality guidelines. The researchers recommended discontinuing the snowmelt studies due to the low concentrations. Ingersoll noted that only snow samples very close to the road were impacted.

2.2.3 Effects on Ecosystem Components

Beyond direct effects on human health, air pollution can be detrimental to ecosystems. Through direct exposure and accumulation, reactive compounds such as O_3, VOC, PAH, PM and inorganic nitrogen may negatively impact plant growth. Also, sulfate (SO_4^{2-}) and NO_3^- are primary contributors to acidic deposition, which can harm fish, decrease biological diversity and degrade forests and soils. The fate of OSV-specific pollutants within Yellowstone National Park have not been fully characterized, but we may infer from what data are available that most potential ecosystem effects from OSV are negligible. This next section is divided into potential ecological sinks for OSV emissions, including the snowpack, forest, soils, runoff, surface water, and biota; potential effects from each pollutant will be discussed.

There have been very limited studies of the effects of air pollution on wildlife. Lab animal studies have shown that animals are also affected by air pollution, but often at concentrations very different than for humans. As with sound, environmental factors that affect an animal's ability to hunt or to detect and avoid predators could influence how well a species does in the wild. Factors such as atmospheric visibility and odor from vehicle emissions are possible influences, but this aspect has not been studied in Yellowstone. The atmospheric particulate matter and hydrocarbons that would affect visibility and odor have been decreasing since the BAT requirement for snowmobiles was implemented.

No effect of OSV-emitted CO is expected on wildlife or vegetation at the atmospheric levels recorded in Yellowstone National Park (less than 3 ppm; Ray, 2010). While wildlife chronic exposure to CO has not been evaluated, we can infer from laboratory studies on animals and humans that the lowest effect levels require ambient concentrations to be much higher (10-50ppm; Raub, 1999).

Ammonia, ammonium, and nitrate

Atmospheric inorganic nitrogen and its deposition in sensitive ecosystems have been widely studied (Likens and Bormann, 1995; Aber et al. 1998; Baron et al. 2006, Bowman et al. 2006). Nitrogen oxides (NO_x) from fossil fuel combustion and ammonia (NH_3) from agricultural land use can contribute to acidification and nitrogen saturation in susceptible landscapes (Aber et al. 1998, Lovett et al. 2009). Recent patterns of nitrogen as nitrate (NO_3^-) and NH_4^+ in wet deposition show steady or slight increases in annual deposition of inorganic nitrogen within Yellowstone National Park (CASTNet, 2010; NADP, 2010) and a significantly degrading trend of increasing NH_4^+ for 1998-2007 (NPS-ARD, 2009) unrelated to OSV use. A comparison of NADP wet-only precipitation chemistry with snowpack chemistry (Ingersoll et al. 2008) illustrates the difficulties of capturing the spatial heterogeneity of inorganic nitrogen deposition in mountainous regions. Long-term monitoring stations in the Rocky Mountains are sparse, tend to be located in open areas (thereby missing vegetative scavenging of dry and occult deposition), and are located at elevations that do not represent the highest deposition sites (Nanus et al. 2003). A spatial model of nitrogen deposition for the Rocky Mountains that took elevation into account (including Yellowstone National Park) estimated total annual deposition of NO_3^- to be less than 3 kg N/ha/yr (Nanus et al. 2003), in agreement with current with CASTNet and NADP measured deposition levels.

Based on general knowledge and understanding of nitrogen sources and effects in the Western United States, additional inputs of nitrogen (as NO_3^- or NH_4^+) from OSV could be important to assess. The nitrogen emissions of OSV should be considered in the context of the background deposition levels. Bishop and others (2009) measured NO_x emissions from OSV, and elevated NH_4^+ has been found in the snowpack near OSV traffic (Ingersoll, 1999), but concentrations dropped rapidly with distance from the road. Cumulatively, nitrogen from all sources contributes to the "loading" of nitrogen to an ecosystem. The incremental amount of OSV contributions to the total loading is relatively small but could be important if the total loading is close to or has exceeded a "critical load" of nitrogen. Critical loads are the amount of pollution that sensitive ecosystems can tolerate before harm occurs.

In the Rocky Mountain region, the most sensitive indicator for critical loads has been changes in diatom assemblages in alpine lakes in the Southern Rockies; this indicator leads to a critical load estimate based solely on wet deposition of 1.5 kg/ha/yr wet N deposition (Baron et al., 2006). Noting that the Greater Yellowstone Ecosystem (GYE) receives lower N deposition than Rocky Mountain National Park, Saros et al. (2010) cored two high-elevation lakes in Shoshone National Forest, WY, part of the GYE, to evaluate shifts in diatom communities that indicated a critical load. The critical load for GYE determined from analysis of diatoms in these cores was 1.4 kg N/ha/yr, similar to that reported by Baron et al. (2006), despite differences in N loading in the vicinity. The authors concluded that "an ecological threshold of 1.4-1.5 kg N/ha/yr wet deposition might be broadly applicable across high-elevation lakes of the western US that are N-limited", and caution that N-limitation status is largely unclear in many alpine regions (Saros et al., 2010).

Critical loads have been estimated based on other indicators elsewhere in the region, though neither in the GYE nor within Yellowstone National Park, and are detailed in Pardo et al., 2011. These critical loads and indicators include: loss of sensitive lichen species (range of estimates: 3-15 kg N/ha/yr), sub-alpine forest soil and foliar chemistry (3-4 kg N/ha/yr, Baron et al., 2000 and Bowman et al., 2006), episodic and chronic freshwater acidification (4 (empirical) – 21 (modeled) kg N/ha/yr), alpine vegetation species composition changes (4-10 kg N/ha/yr) (Pardo et al., 2011 and references therein). Note that these critical loads are for total (wet + dry) nitrogen deposition, while the critical loads for diatoms, discussed above are calculated for wet-only deposition.

Soils

The soils of Yellowstone National Park were mapped between 1988 and 1996 by Rodman and others (National Park Service, 1997). Shallow inceptisols with low base saturation predominate near the Yellowstone snow road, though chemical composition of these soils has not been characterized. There are little or no direct data on OSV effects on soils within Yellowstone National Park.

In general, low base saturation indicates that acid inputs from infiltration could push acid cations (H^+, Al^{3+}) into solution. Soil microbiology and nutrient exchange mechanisms affecting plants can be altered by acid loading, but as noted above regarding local snowpack chemistry, the acid neutralizing capacity (ANC) of snow, and likely runoff, is increasing (Figure 2-1). Infiltration of dilute yet positively buffered snow as is found in Yellowstone National Park would likely not affect soil acid status. We can also infer that any potential OSV effects on chemical composition of soils would be imperceptible in part due to the geothermal and fire regimes within Yellowstone. The natural patterns of disturbance (such as fire, grazing and drought) likely mask any changes in soil nitrogen status from total (not just OSV) atmospheric deposition, although there seems to be little research in this area. We can also infer that because the groomed snow road overlays the main summer road, soil health issues from compaction or erosion are not expected at Yellowstone National Park as a result of OSV use.

Biota

Air pollution can have significant impacts on biodiversity across many different ecosystems (Lovett et al 2009). In general, forests are affected by both air quality and soil health parameters. Potential damage to trees from exposure to CO, O_3, and PM has been well established elsewhere, but in general the thresholds for damage are higher than what current OSV emissions would originate (for example: Lovett et al 2009; US EPA, 2009). We have inferred that landscape effects from OSV-emitted pollutants are unlikely, except for nitrogen; therefore little effect is expected for terrestrial plants or animals.

Nitrogen deposition may be of concern in general based on wet-only deposition of total inorganic N measured by NADP at site WY08, Yellowstone National Park-Tower Falls, which has been ~ 1 kg/ha/yr since 1989. This site is removed from OSV traffic in Yellowstone and unlikely to represent effects of OSV emissions. However, NPS-ARD (2009) found a statistically significant increasing trend in NH_4^+ in wet-only deposition using 1998-2007 NADP data. The five-year average dry deposition of N (HNO_3 + NO_3^- + NH_4^+) measured by CASTNET (located near Lake Village) was 0.2 kg/ha/yr, and for a total wet + dry N deposition of 1.2 kg/ha/yr for Yellowstone (US EPA, 2010). This value is below the critical load estimate, 1.4-1.5 kg/ha/yr for the most sensitive indicator, diatom assemblages (Pardo et al. 2011, Saros et al. 2010, Baron et al. 2006). However, CMAQ (emissions-transport) modeling for 2002 (Sullivan et al. 2011) provides estimates of total N deposition that range 2-10 kg N/ha/yr, much greater than those from wet deposition only NADP station. The CMAQ deposition modeling is unverified and should be taken as a relative indicator. The Nanus report with spatial estimates of deposition suggests the Tower Junction site is not representative of the all of the park.

The best estimate for total (wet and dry) N critical loads at which sensitive ecosystem first begin to change in the GYE area may be around 2 kg N/ha/yr (Blett, pers. comm. 2011). Additional changes in ecosystem condition may take place as N deposition increases (4 kg N/ha/yr for changes to alpine plants). The recent wet + dry estimate at Yellowstone National Park is approximately equal to the critical load (wet deposition only) for changes to diatoms, and less than half of the critical load for changes to alpine plants. However, (1) wet + dry deposition is difficult to measure across heterogeneous, mountainous terrain; (2) dry deposition as measured by CASTNET does not take into account enhancement of dry deposition by forest canopies, as has been demonstrated in eastern forests (e.g., Weathers et al., 2006) or vegetation differences compared to the monitoring site, and (3) nitrogen deposition may be underestimated by NADP monitoring in alpine regions (Nanus et al 2003). Combined with the significantly increasing trend in NH_4^+ deposition at Yellowstone and the potential for “even slight increases in atmospheric deposition” to lead to measurable changes in ecosystem properties (Baron et al.

2000), better quantification of OSV contributions to N budgets within YELL to compare more directly to critical load estimates are warranted. Forthcoming results from a preliminary risk assessment lists Yellowstone as one of the I&M National Park Networks (of 32 total) in the quartile most sensitive to N enrichment, (Sullivan et al., 2011). The ranking system includes exposure to N (low for YELL) sensitivity of Park resources (very high for YELL), and Park protection variables (very high for YELL) rather than using measured ecosystem variables to indicate critical loads, as in Pardo et al. (2011).

Within Yellowstone, natural conditions due to fire, geothermal activity, and ecosystem heterogeneity have created specific biological niches that make traditional bioassessment models ineffective (Arnold, 2011, pers. comm.). Acidic springs (pH ~3) flow into calcium carbonate dominated rivers (pH>7), hot groundwater (30° C) flow into cool surface waters, and dilute streams mix with high ionic strength sources to create a dynamic and highly variable aquatic environment (McKlesky et al 2010). Biota have adapted to specific hydrogeochemical conditions, some of which would be considered toxic or impaired anywhere else (Ball et al 2008). Given these conditions it is unlikely that current OSV emissions would have a distinguishable effect.

2.2.4 Aquatic Resources

Snowpack

The most extensively studied abiotic part of the winter ecosystem at Yellowstone National Park is the snowpack; the snowpack chemistry provides data that are directly relevant to this assessment. The chemical influence of OSV on the snowpack has been monitored since 1993 along the West Entrance Road, along the Old Faithful access road, and in the vicinity of Sylvan Lake on the East Entrance Road (Ingersoll, 1999; 2008), thus capturing the pre- and post-years.

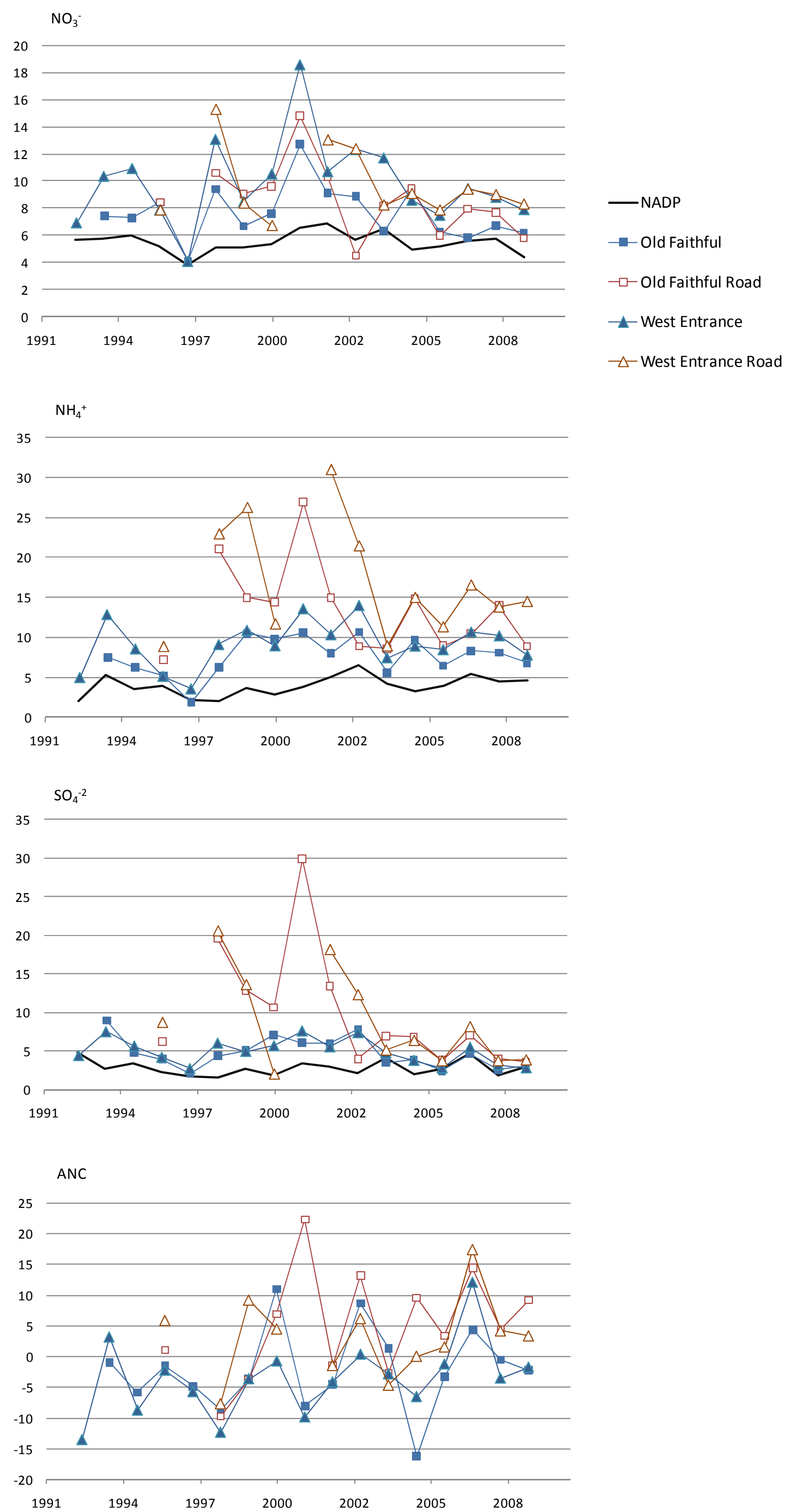

Figure 2-1. Seasonal snowpack and wet-only winter deposition (black line) concentrations of NO_3^-, NH_4^+, SO_4^{2-}, and ANC in μeq/L. Open symbols are from in-road snowpack samples, closed symbols from nearby; squares and triangles are from the Old Faithful and West Entrance locations, respectively.

Snowpack (wet+dry deposition) SO_4^{2-}, NH_4^+ and NO_3^- concentrations are slightly higher than in the wet-only deposition samples measured as part of NADP (Figure 2-1 data retrieved from http://co.water.usgs.gov/projects/RM_snowpack/html/CentralRegion.html and http://nadp.sws.uiuc.edu/sites/siteinfo.asp?net=NTN&id=WY08). Some snowpack samples are taken from *in* the snow road, and others nearby. A comparison of snowpack samples near the West entrance (both in-road and nearby) and near Old Faithful (in-road and nearby) indicates no pattern of OSV influence on NO_3^-; however, in-road NH_4^+ concentrations since 2004 are on average 3.5 μeq/L higher than nearby samples. SO_4^{2-} and acid neutralizing capacity (ANC) are also slightly elevated in in-road samples compared to nearby samples (Figure 2-1). ANC is a measure of the buffering capacity or the ability to neutralize acid anions like SO_4^{2-} and NO_3^-. Throughout the period of measurement, the acid neutralizing capacity (ANC) has increased at all sites as SO_4^{2-} in ambient snowpack has decreased (Ingersoll et al 2008). Decreasing SO_4^{2-} and increasing ANC in many surface waters have been observed in the eastern US in response to emissions cuts mandated by the Clean Air Act Amendments (Kahl et al. 2004). It is difficult to determine whether observed changes in snowpack chemistry are related to BAT implementation or broader influences such as regional emissions declines. Increased ANC in snowmelt may have positive effects for acid-sensitive surface waters, which will be discussed below.

VOC concentration in the snowpack was also measured, providing direct evidence for Yellowstone (Ingersoll, 1999). While the pilot data for VOC samples had contamination issues, particularly for toluene (Ingersoll, 1999), there was a notable difference between VOC concentrations in in-road and nearby sites. Later, it was determined the toluene in samples may have been a byproduct of forest fire residues in underlying soil (Arnold and Koel, 2006). Generally, likely sinks for VOC in snow would be VOC in spring runoff and potentially some soil infiltration. A study of natural VOC (such as terpenoids) in snow in Finland demonstrated that soils were a source of VOC to the snowpack, inferring that exchange between soils and snow could occur freely throughout the winter (Aaltonen et al 2010). The analysis of VOC in the snowpack should be updated to reflect BAT implementation, although snowmelt data from 2003-2004 indicated VOC concentrations were low and did not exceed EPA standards for surface water (Arnold and Koel, 2006).

Inferential evidence from a study of snowmobile effects on VOC concentration in snow in Vermont (VAST, 2010) points towards negligible effects of OSV traffic on snow chemistry. Snow samples from reference and in-trail sites showed no variation in VOC concentrations, and most VOC concentrations for all samples were below the detection limit of 2 μg/L.

A USDA Forest Service Rocky Mountain Research Station study (Musselman, 2007) in the Snowy Range of Wyoming also measured water chemistry and snow density from snow samples collected on and adjacent to a heavily used snowmobile trail. The dominate snowmobiles in this study used 2-stroke engines. Snow on the trail was denser and more acidic with higher concentrations of sodium, ammonium, calcium, magnesium, fluoride, and sulfate than in snow off the trail; however all levels were within acceptable limits and well below levels that would adversely impact aquatic systems. The study also found that snowmobile activity had no effect on nitrate levels in snow. Ambient NO2 concentrations were higher (3-5 ppb) on weekends when snowmobile activity was greatest.

Runoff

As a snowpack melts, the accumulation of pollutants from the winter season may have implications for air, surface water and soil quality. Generally, the fate of substances in the snowpack are 1) re-emission (e.g. CO (Constant et al 2008) and VOC (Aaltonen et al 2010)) or 2) runoff of acidifying solutes and particulate matter into soils and surface water.

The effect of snowmobile emissions on the chemistry of snowmelt water has been studied in Yellowstone National Park starting in 1999 (Ingersoll) and followed up during two winters, 2003, 2004 at locations near the road for the west entrance, Madison Junctions, and Old Faithful (Arnold 2006). VOC concentrations were often below the reporting limits (less than 0.1 μg/L), but detected concentrations of benzene, ethylbenzene, m- and p-xylene, o-xylene, and toluene (0.1-3.4 μg/L) that were associated with high OSV traffic at Old Faithful. Metals (lead, Hg, for example) have not been measured in spring runoff, and may be of interest to determine loading to surface water. During the course of the study, VOC concentrations of snowmelt runoff in Yellowstone National Park were well below levels that would adversely impact aquatic systems. Researchers recommended that continue runoff measurements were unlikely to be productive.

Despite potentially elevated acid anions in the snowpack, the pH of runoff (pH 5.3-7.4) was similar to that found in the snowpack (pH 4.9-6.3) and at the NADP site (pH~5.2) for the time period, possibly indicating that OSV traffic would have little acidifying affect on local streams, some of which are highly buffered due to groundwater inputs.

The conductivity of runoff varied by site (15-175 µS/cm) but in all cases was greater than precipitation and snowpack measurements (3-5 µS/cm, on average), but well below the range seen in nearby rivers (100 µS/cm to much greater near thermal features) (Arnold and Koel, 2006; Ingersoll, 1999; NADP, 2010; Koel et al 2010). This suggests that measured runoff chemistry reflects snowmelt that has been in contact with soils and/or vegetation, thus the values of all measurands in runoff were potentially influenced by the interactions. Therefore, direct snowpack measurements are likely more representative than runoff for changes in conductivity related to OSV.

Surface water

Surface water chemistry near the snow road (and through much of Yellowstone National Park) is dominated by carbonate chemistry from groundwater and thermal inputs. The road follows the Madison and Firehole Rivers, both which have chemical signatures dominated by calcium bicarbonate with high relative ion concentrations of sodium and chloride (Koel et al 2010). These are not dilute systems, thus the general expectation is that the low ionic strength runoff from the snowpack would not affect surface water pH or ANC.

Directly measured lake ANC concentrations within Yellowstone National Park indicate that nearly all lakes in the vicinity of the snow road are highly buffered (ANC often in excess of 200 µeq/L) in part due to bedrock geology (Nanus et al 2005). Additionally, the modeling of the acid sensitivity of lakes within Yellowstone found little evidence to suggest that acid inputs would affect surface waters (Nanus et al 2009).

Inputs of VOC from OSV use have been determined to be low within Yellowstone National Park (see above, Arnold and Koel, 2006), and PM concentrations are likely very dilute in snowpack runoff compared to ambient stream conditions within Yellowstone National Park.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) are nearly ubiquitous in the environment; a subset of PAH are derived from petroleum products. High concentrations of PAH in runoff from parking lots and roadways have long been associated with declines in water quality (Gjessing, 1984) and have been identified as needing further study within Yellowstone (Arnold and Koel, 2006). A regional study found anthropogenically derived PAH concentrations in snow, vegetation, water, fish and sediments from surrounding parks (Landers et al. 2008), although the study did not attribute the PAH contamination directly to gasoline combustion. It is unknown whether OSV use within Yellowstone National Park contributes to anthropogenic PAH, although a recent study in Vermont concluded that snowmobile traffic on trails did not contribute to PAH levels in runoff or soils (VAST, 2010).

2.2.5 Climate and Other Resources

Other pollutants

Of minor concern are carbon dioxide (CO_2- a greenhouse gas related to global climate change) and ozone (O_3- a strong oxidizer often formed in the presence of VOCs and nitrogen oxides). High levels of CO_2 do emanate from some thermal features within the park, and CO_2 emission sources, natural or anthropogenic, do not have local or acute effects. In general, ozone undergoes a complex atmospheric formation and destruction chemistry, which causes ozone concentrations to vary widely on geographical and temporal scales. Recent work near Wyoming gas fields has demonstrated winter ozone production (Schnell et al. 2009), when previously ozone monitoring was only considered necessary from May-September (Pinto, 2009). Prior to BAT implementation, Sive et al. (2003) found that OSV emissions (probably from snowcoaches) at a location near Lake Village lead to O_3 interactions. Enhancement of winter ozone has not been observed with the long-term monitoring nearby.

Recent studies have demonstrated that mercury (Hg) emissions from gasoline motor vehicles are measurable (2-17 ng/mi; Won et al. 2007), variable depending on driving conditions (0.3-1.5 ng/mi; Hoyer et at 2004), and are associated with elevated environmental Hg concentrations near traffic (Lynam and Keeler, 2006). Hg deposition due to OSV traffic has not been evaluated, but hydrothermal features within the park (Boyd et al. 2009; Abbott, 2004) and regional forest fires (Hall et al. 2006) are likely to provide the greatest contributions of Hg to the ecosystem.

Section Summary

Atmospheric and snowpack concentrations of OSV emitted pollutants have decreased in response to BAT implementation, and it appears that current emission levels of all OSV likely do not compromise ecosystem health in a measurable way.

Limitations of this analysis, and areas that may need additional study, include:

- Research into air quality effects on ecosystems generally refer to pollutant concentrations not seen within Yellowstone National Park but don't rule out chronic exposure effects.
- Many described effects of emissions are pollutant- and species-specific whereas ecosystems are exposed to many stressors.
- Naturally occurring sources of sulfur, ammonia and Hg within Yellowstone National Park make measuring ecosystem effects of atmospheric deposition difficult.
- Data on the effects of these pollutants within Yellowstone National Park are scarce and have not been compared to those in similar ecosystems that do not have OSV use, thus the interpretations provided are highly generalized and non-specific.
- Nitrogen loading from OSV use has not been quantified, and should be a focus of continued monitoring, in part because of regional increases unrelated to OSV.

2.3 Air Quality Monitoring and Studies Within Yellowstone NP

2.3.1 Air Monitoring Results

The park monitors ambient CO and $PM_{2.5}$ concentrations at two locations within the park, the west entrance and Old Faithful. For the winters of 2009-201 and 2010-2011 there is NOx data from the west entrance. Additional air quality measurements are made near Lake Village at the water tank (ozone, sulfate, nitrate, nitric acid, and visibility) and at Tower Junction (wet deposition) (See map for locations in Appendix A, Figure 2-1).

Background conditions, regional conditions:

Carbon monoxide

Measured overnight CO concentrations and samples taken away from the trafficked roads suggest the background concentration for CO in Yellowstone is roughly 0.15 ppm (Ray, 2007; Sive et al., 2003) Rural CO measurements in western states by several researchers have been used to estimate the CO background concentrations as 0.120 ppm (Warnick, 2001; Brasseur et al, 1999). Measurements by researchers at Rocky Mountain NP have estimated the background at 0.110 to 0.130 ppm (Carriarro, 2010) and at the nearby Niwot Ridge site at 0.117 ppm (NOAA, http://www.temis.nl/airpollution/no2.html). Satellite measurements for the winter months show a regional concentration of CO of 0.10 to 0.15 ppm (NASA, http://www.temis.nl/airpollution/no2.html). Overnight CO concentrations and measurements during no traffic periods at Yellowstone are very close to the expected regional CO background concentration.

Particulate Matter

Particulate matter measurements have been conducted in Yellowstone for over two decades by the IMPROVE program and since 2002 by a monitoring program using continuous $PM_{2.5}$ analyzers at Old Faithful and at the west entrance site. The deposition and sink processes for fine particles are much slower than for reactive gaseous compounds, so overnight concentrations at the measurement sites in Yellowstone don't necessarily go to near background concentrations. Local, non-mobile sources also contribute to the measured PM2.5 concentrations (Ray, 2006, 2007; Sive et al, 2003). The following estimates based on averages from periods when OSV was absent are our best estimates for the Yellowstone regional background, Table 2-7 (Ray, 2010)

Season	1996-2003 Lake IMPROVE Mean daily PM2.5	Dec 2005-Mar2008 West Entrance Max daily	98th percentile	seasonal mean	Dec 2006-Mar 2008 town of West Yellowstone Max daily	98th percentile	seasonal mean	Dec 2005-Mar 2008 Old Faithful Max daily	98th percentile	seasonal mean
winter	1.4	9	7	2	29	27	8.2	8	7	3
spring	3.0	6	5	2	- -	- -	- -	- -	- -	- -
summer	4.7	33	18	5	- -	- -	- -	- -	- -	- -
fall	1.8	27	22	4	- -	- -	- -	- -	- -	- -

Units of ($\mu g/m^3$)

Table 2-7. Seasonal mean $PM_{2.5}$ concentrations from the water-tank IMPROVE station for the period 1996 – 2003 compared to daily $PM_{2.5}$ statistics at other sites.

Nitrogen dioxide

Background concentrations of NO_2 over the continental US have been estimated by EPA as part of the support documents for the NO_2 NAAQS (EPA, 2009). The estimated background is 0.001 ppm or less. Nitric oxide (NO) in rural locations away from sources is usually even less (< 1 ppb range). Direct measurements of NOx in the park suggest contributions of NOx from outside the park, from stationary sources within the park, and from winter mobile sources (OSVs) (Sive, 2003; Jensen & Meyer, 2006; Ray, 2010). Maximum observed NO2 at Lake Village was a short spike at 10 ppb. Overnight NO2 was 1.8 to 2.2 ppb and the mean daytime concentrations were 3-5 ppb.

Ozone

Ozone shows a seasonal pattern with a peak in spring of about 75 ppb, summer concentrations with lower peaks (~65 ppb), and winter values in the 35-50 ppb range. There is no indication of elevated ozone concentrations during winter nor of NO titration of ozone overnight (Ray, 2010). A brief period of monitoring at Lake Village (Sive, 2003) with ozone and NOx analyzers confirmed the ozone measurements being taken at the water tower site a ½ mile north. The researchers saw one night when ozone went down to 15 ppb and suggested it might have been due to reaction with NO, however, the decrease in ozone started mid-day which suggests a weather explanation.

Hydrocarbons

Measurements of hydrocarbons, CO, and NOx were made during 2002 and 2003 at multiple sites within Yellowstone to determine the spatial variability (Sive et al,. 2003; Yong et al, 2010). This was prior to the managed use era. In 2003, 4-stroke snowmobiles were becoming more common (with estimates ranging up to 50% of snowmobiles). Hydrocarbon concentrations were found at considerably above the background concentrations. The aromatic organics including benzene, toluene, and xylenes were found at unhealthy concentrations at the west entrance and other locations along OSV routes. The mix of organic compounds provided a fingerprint showing recent (within a day) emissions predominately from 2-stroke engines. Using alkyl nitrate concentrations as tracers, the researchers showed that only small amounts of organics were being transport over long distances to the park.

Organic pollutants were being transported into the park from locations along the western park boundary. Measurements of hydrocarbons within the town of West Yellowstone indicated high concentrations from 2-stroke engines. Early morning samples were compared to mid-afternoon samples along the OSV routes. The 5am samples were low in CO (mean 0.13 ppm) and hydrocarbons. indicating CO concentrations at regional background levels and that some carryover occurred with the hydrocarbons. Measurements at different distances from the road (50m and 500 m) indicated a rapid decrease in concentrations. Both these findings point to OSVs as the source. The largest concentrations were at congestion points such as the west entrance and the Old Faithful area.

Monitoring records

The NPS Air Resources Division and the Montana Department of Environmental Quality have monitored CO and $PM_{2.5}$ in Yellowstone since 1998 (Ray, 2009). Only short term measurements were made for CO concentrations prior to that (NPS ARD, 2002). Measured concentrations of the second highest eight-hour average CO improved from 1998-1999 (4.3 ppm) to 2008-2009 (1.1 ppm) by a 74% reduction. For winter 2009-2010, the particulate concentrations are 17% of the 24-hour $PM_{2.5}$ standard; $PM_{2.5}$ has decrease by greater than 55% since the late 1990's (Ray, 2010). Figure 2-2 summaries data reported in annual monitoring reports (Ray, 2009; Ray, 2010) for the second highest daily maximum hourly CO concentration and the 98^{th} percentile of the hourly $PM_{2.5}$ concentrations. Since the NAAQS is expressed for annual periods and generally averaged over 3 years, an exact comparison to the standards isn't possible when OSV traffic is only during a 3 month winter season, therefore, relevant statistic for the winter season only are being used for the comparison.

Considering the diurnal patterns for the air pollutants at Yellowstone (Ray, 2007), the shorter-term hourly values were chosen as most representative of peak conditions that might be unhealthy or harm resources. The mean second maximum winter CO prior to 2003 was 14.3 ppm (peak 17.4 ppm) which was reduced to a mean value of 3.1 ppm from winter 2003-2004 onward; a 78% reduction in CO. The $PM_{2.5}$ followed a similar reduction in concentrations at the West Entrance (Figure 2-4) with the $PM_{2.5}$ of greater than 16.9 ug/m3 going down to a mean of 7.1 ug/m3; a greater than 57% reduction in $PM_{2.5}$.

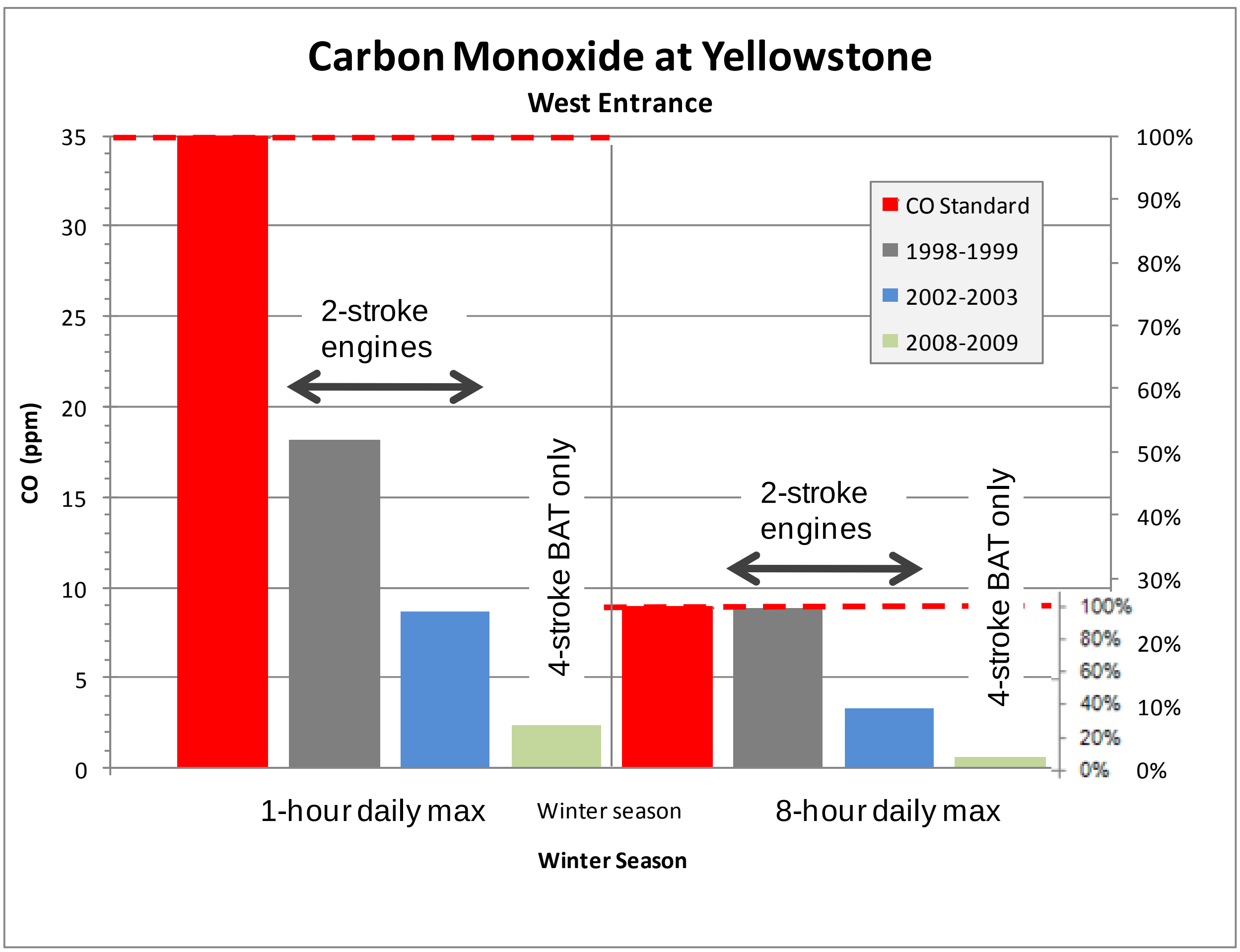

Figure 2-2. Comparison of measured CO concentrations during winter to the federal standard. Right axis is the percentage of the 8-hour standard. Winter 2008-2009 CO less than 20% of the 8-hour standard.

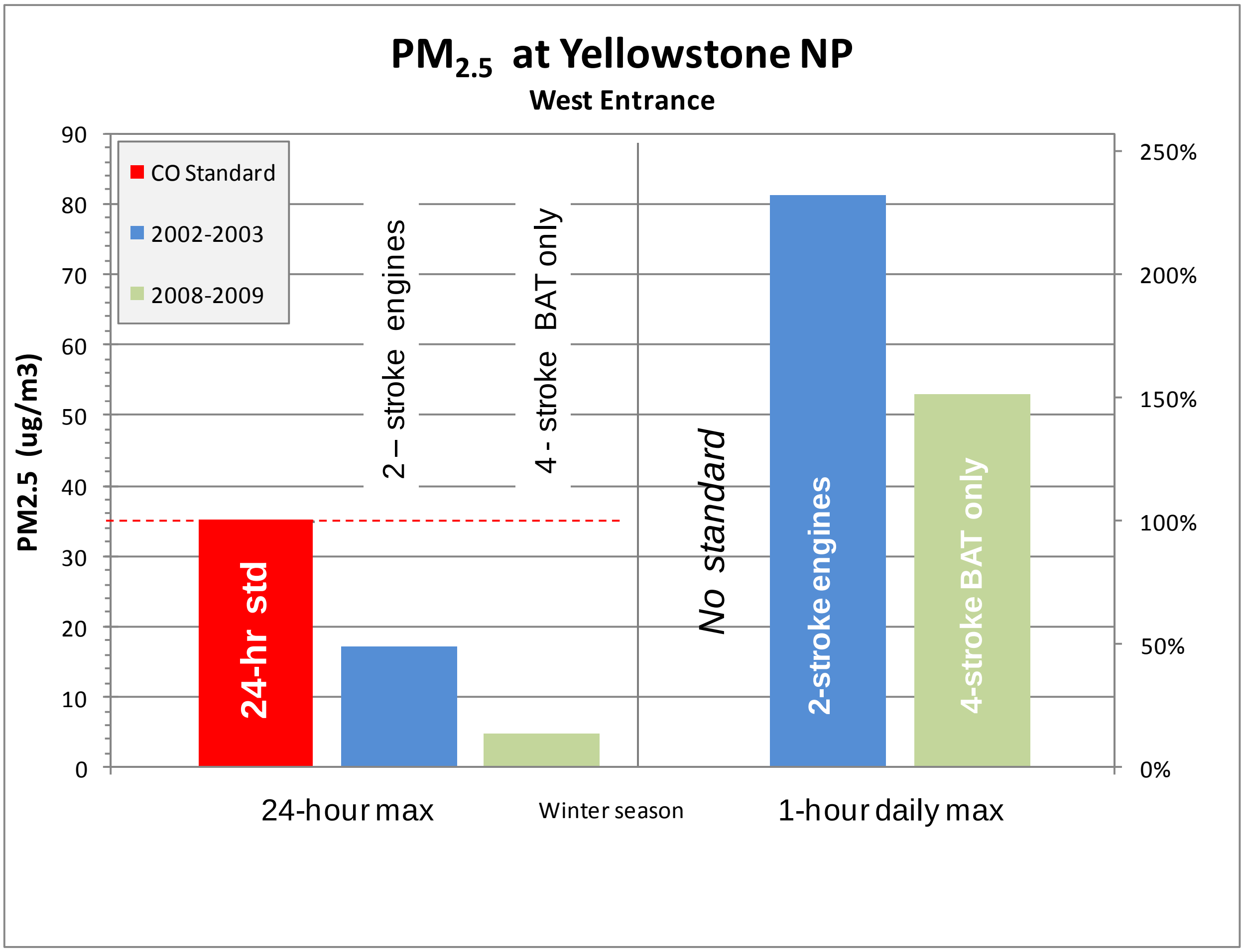

Figure 2-3. Comparison of measured $PM_{2.5}$ concentrations during winter to the federal standard. Right axis is the percentage of the 24-hour standard.

Air quality at YNP meets the national standards set by the U.S. Environmental Protection Agency (EPA) for CO and $PM_{2.5}$ to protect human health, but CO in the park ranges above background CO concentration for YNP, which is estimated at about 0.120 ppm (Ray 2009, 2010). Results of winter 2008-2009 air monitoring at the park reveal diminishing daily average concentrations of $PM_{2.5}$ within the park, while concentrations within the Town of West Yellowstone (outside the park) have remained constant or increased slightly over previous years.

Hourly and eight-hour average CO concentrations have recently decreased at the West Entrance while remaining relatively constant at Old Faithful (Figure 2-4).

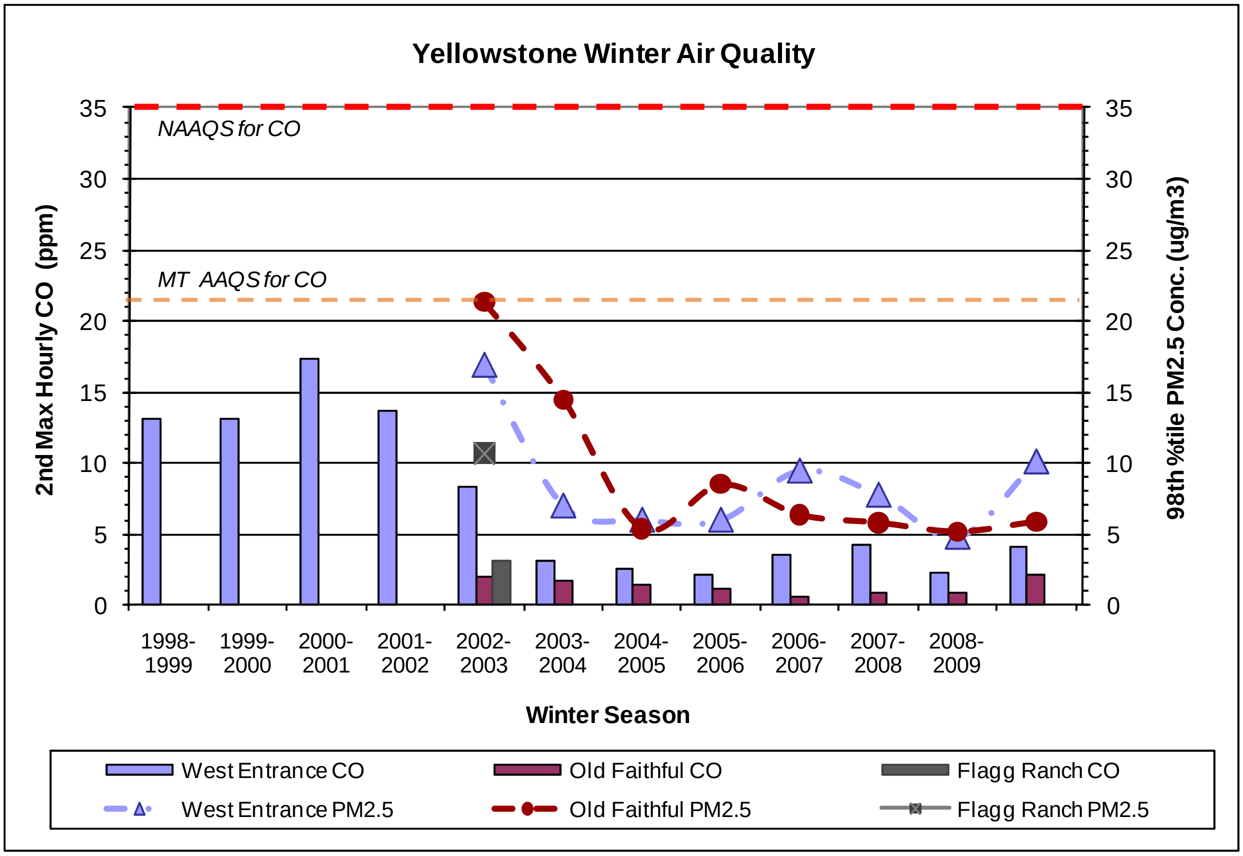

Figure 2-4. Air quality changed significantly after winter 2001-2002 as seen by the change in both CO and $PM_{2.5}$ concentrations. The winter 2002-2003 was a changeover period between 2-stroke snowmobiles and 4-stroke snowmobiles with about a 50% mix.

Since OSV traffic density was not the same during the periods when the monitoring occurred, the traffic volume per day and even per hour needs to be considered. Overall seasonal traffic is available from the NPS (Street, 2010; http://www.nature.nps.gov/stats/) while hourly traffic records have been collected by the NPS gate staff (Hektner,2010) and by ARD (Ray,2010; Ray, 2008; ARS, 2010). The park has prepared a summary document (Sacklin, 2010) on OSV traffic counts. Information on OSV traffic volume on different road sections was used in preliminary scenario modeling for the 2007 EIS. (Wu 2006). Table 2-8 gives the winter totals of OSV traffic. Figure 2-5 does a breakdown of OSV traffic by type of vehicle. A steep decrease in snowmobile traffic occurred for the 2002-2003 and 2003-2004 winters.

Table 2-8. OSV entrance data for all Yellowstone gates for winter of seasons.

all entrances			
Year	**Snowmobile totals**	**Snowcoach totals**	Total
1997-1998	60,110	1,326	61,436
1998-1999	62,878	1,396	64,274
1999-2000	62,531	1,535	64,066
2000-2001	67,653	1,591	69,244
2001-2002	69,196	1,605	70,801
2002-2003	47,799	1,653	49,452
2003-2004	22,423	2,058	24,481
2004-2005	18,364	2,201	20,565
2005-2006	21,916	2,463	24,379
2006-2007	24,516	2,448	26,964
2007-2008	23,814	2,653	26,467
2008-2009	17,252	2,389	19,641
2009-2010	16,491	2,525	18,979

Data from the NPS Public Use Statistic web page at **http://www.nature.nps.gov/stats/viewReport.cfm**

In addition to BAT requirements and lower snowmobile numbers, commercial guiding and changes in entrance station procedures to prevent idling by groups of snowmobiles were instituted in winter 2004-2005. The number of visitor snowmobiles has decreased from over 47,000 in the winter of 2002-2003 (about 50% BAT compliant) to about 18,000 (100% BAT and guided) in winter 2004-2005.

As a result of BAT entry requirements and reduced snowmobile numbers, air quality quickly improved from 2002 to 2004, exhaust odors decreased and the average snowmobile gas mileage approximately doubled (Bishop et al, 2007; Ray, 2008) .

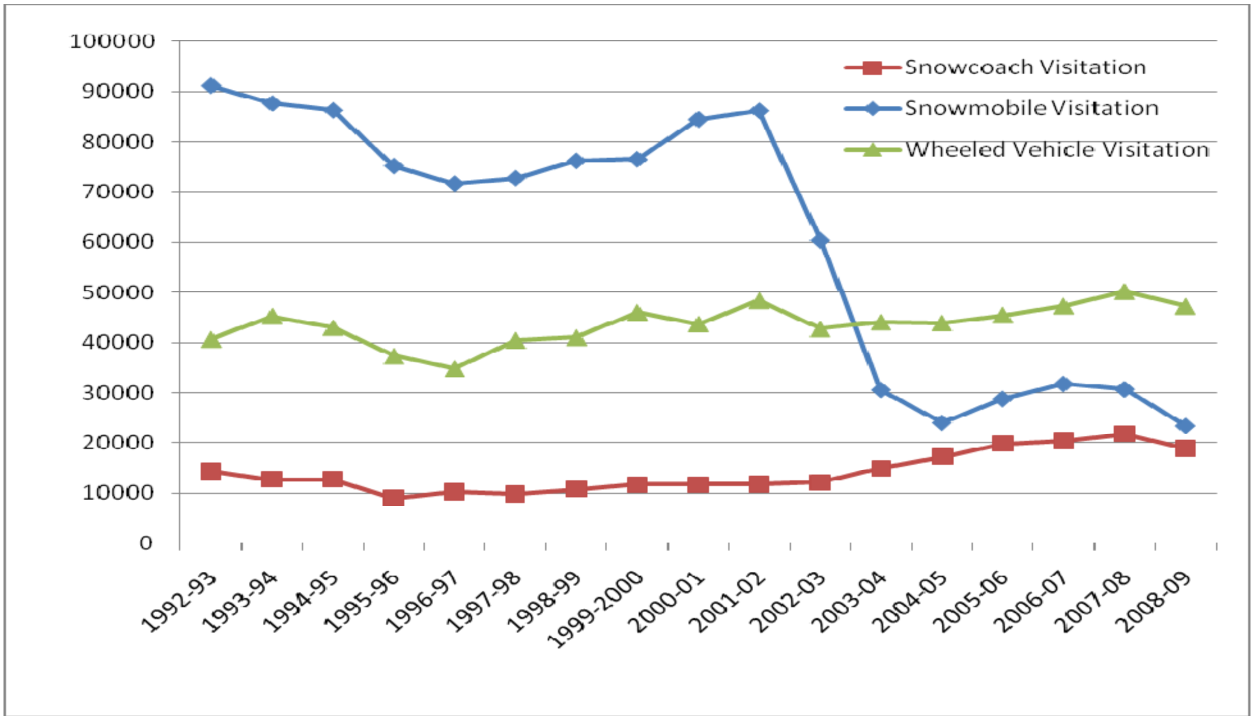

Figure 2-5. Total winter visitor traffic to Yellowstone dropped significantly in the winter of 2002-2003 and again in the winter of 2003-2004. A corresponding drop in CO and $PM_{2.5}$ concentrations were seen at the West Entrance monitor for those winters. Snowcoach usage has increased above historic levels since the winter of 2002-2003.

The number of snowcoaches in each year complicates the picture. The BAT snowmobiles have a much smaller range of emissions (See Table 2-5). The snowcoaches have a broad range of ages, engines, body and tread types, and pollution controls. Prior to 2004, there were no limits on the number of OSV entering the park. Average peak day (1992-1999) was 975 and average was 554 snowmobiles per day through West Entrance. Snowcoaches were 19 and 9, respectively in those years. (NPS, 2003) and the number of snowcoaches in use has increased yearly since 2003. The OSV entry 2004-2009 limits were 400 snowmobiles and about 40 coaches. In the 2009-2010 winter period, the West Entrance OSV limits were 160 snowmobiles and about 40 coaches. One snowcoach is roughly equal in emissions/passenger to 7 snowmobiles based on typical passenger loading. Estimates of total emissions by OSV type in Yellowstone, indicate that the winter emission totals were roughly equal for snowmobiles and snowcoaches (Bishop, 2008; Wu, 2006). Recently, (Table 2-8) the number of BAT snowmobiles have decreased and the number of unregulated-emission snowcoaches have increased.

Although there are some variations based on snow and weather conditions, the winter OSV use pattern is highest OSV activity (see Figures 2-6a & 2-6b) between the Christmas holiday and over the new year's holiday, increased usage over the period just before the MLK holiday, and increased usage around the President's Day holiday in February. The last two weeks of the season in March has a tail-off in activity even though there is usually snow on the ground. Snowmobile and snowcoach daily activity patterns through the season are similar. Snowcoach numbers have increased from the historic average of 15 per day to an average of 35 per day. The peak day recorded 68 snowcoaches operating in the park in 2010-2011 winter.

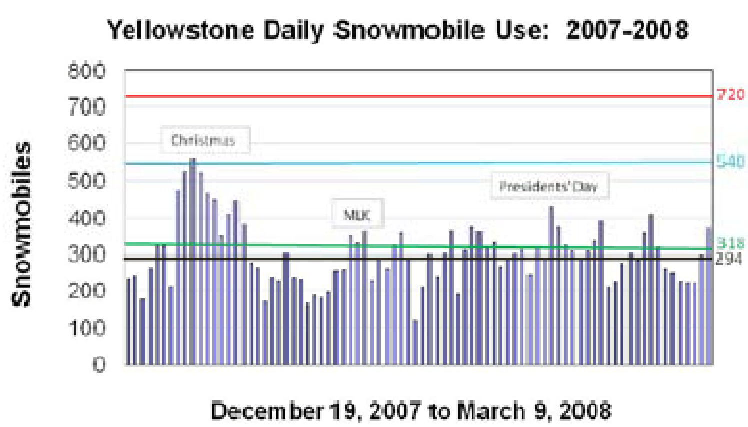

Figure 2-6a. Daily snowmobile entry counts for winter 2007-2008.

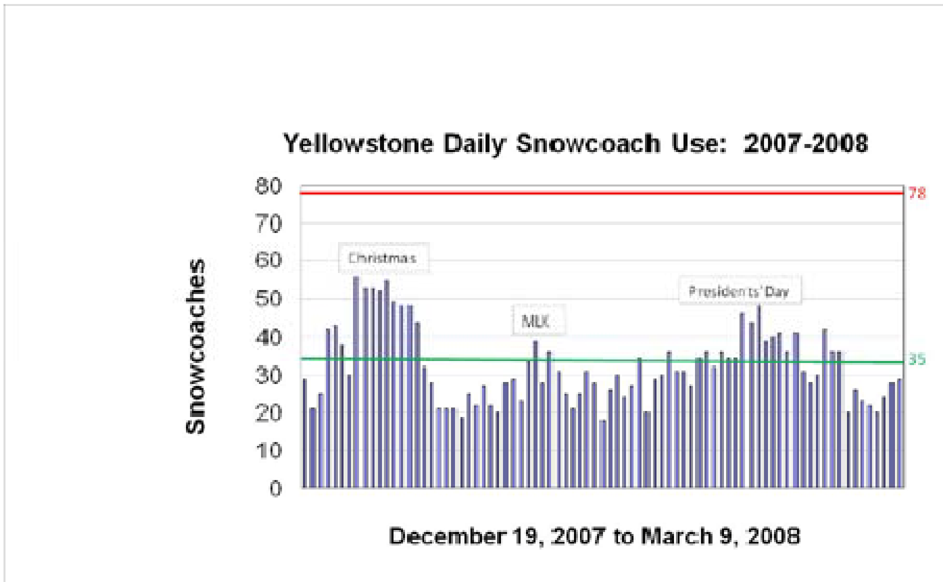

Figure 2-6b. Winter 2007-2008 daily OSV traffic data for Yellowstone.

Air quality concentrations should change with the number of vehicles. However, other factors, including traffic density, amount of time a vehicle was in the area, etc., will also influence immediate and short- term air quality conditions. Daily and longer term variations in concentration are dependent on weather, winds, and boundary layer height (Cain & Coefield, 2001). Rough relationships between traffic volume and concentrations can be derived from the observations and the computer modeling (Ray, 2007; ARS, 2007).

Aside from meteorology, another confounding factor is that the park entry requirement for BAT currently only applies to commercially guided snowmobiles, as administrative (including concessioner, contractors, staff personal vehicles, etc.) snowmobiles are not yet required to have BAT, nor are snowcoaches. Administrative OSVs account for 8% of snowmobiles on the road corridors. The park estimates that about 70% of administrative snowmobiles are currently using BAT; this number is up from the approximately 50% in 2005-2006 (Sacklin, 2010 personal comm.).

The relationship between OSV entry counts and the observed CO concentrations is explored below in Figure 2-7. The linear relationship is derived from the west entrance OSV counts using

10-minute average data for both the CO monitor and the traffic counter. (Figure 2-7). Weather conditions such as wind direction and speed, temperature, snow, and boundary layer height effect the dilution of the local emissions near the gate so that observed CO concentrations vary from day to day (Ray, 2010). The shaded area is where most of the expected CO concentrations occur based on the hourly traffic through the West Entrance.

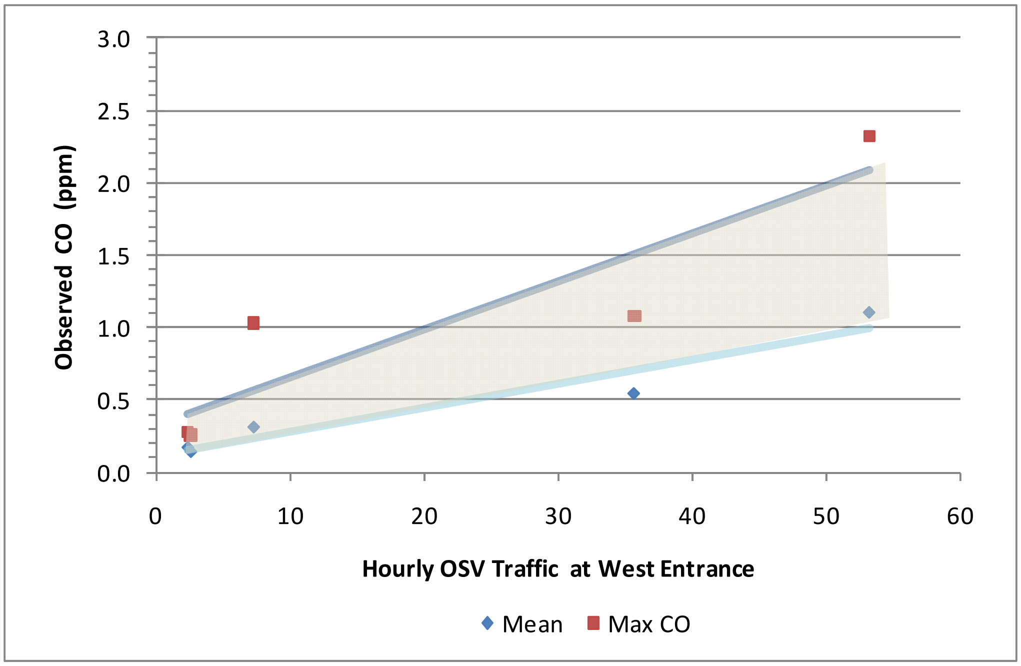

Figure 2-7. Relationship of hourly average traffic volume at the West Entrance with the observed CO concentrations. The shaded area is the range of CO that depends on weather conditions. Uses monitoring data from the winter 2009-2010 mix of BAT snowmobiles and unregulated snowcoaches.

Modeling

Scenario modeling was used for the previous EIS (NPS, 2007) to predict emission levels and concentrations under what was considered the worst weather conditions for air quality. Emission rates for snowmobiles and snowcoaches were taken from the literature values then available. Since several different traffic levels were modeled, it is possible to extract some information about the expected changes in pollution concentrations with traffic volume. In this exercise, it was assumed that the modeling results are proportional to the emissions of the vehicles and that an "equivalent snowmobile" emission level could be used. This is to account for the different mixes of snowcoaches to snowmobiles. The model run with snowcoaches only and the emission rates for snowcoaches were used to calculate how many equivalent BAT snowmobiles each snowcoach represented. The results are plotted in Figure 2-8 for both the 1-hour CO and the 8-hour CO at the West Entrance. For reference an equivalent curve for 2-stroke snowmobiles has been added. The steeper the slope of the line the more emissions there are per OSV. All the model lines have intercepts close to the CO background concentrations. The key point from both the observation and the diffusion modeling approaches represented in Figures 2-7 and 2-8 is that increasing numbers of either snowmobiles or snowcoaches will increase the air pollutant concentrations. If the emission levels of either type of OSV are reduced then the effect of more traffic would be reduced.

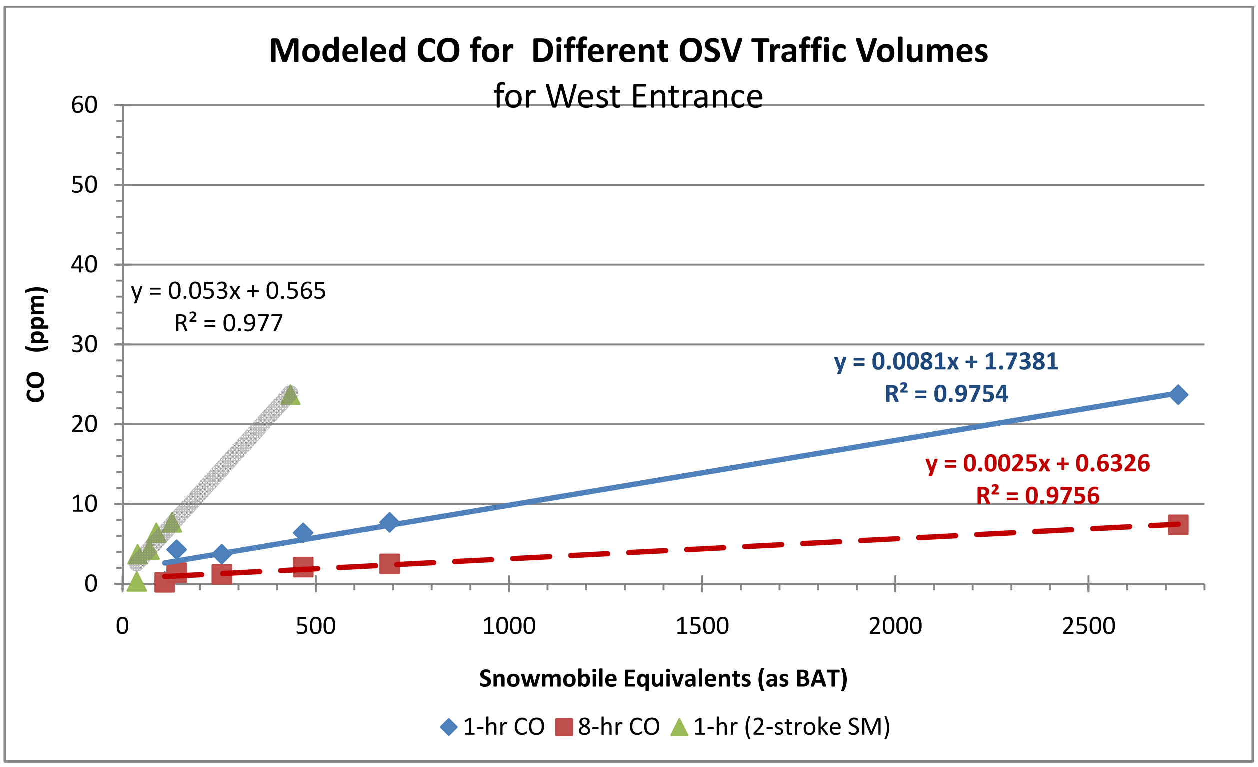

Figure 2-8. Estimates from modeling of the effect on ambient air quality for CO with changes in daily snowmobile volume. Calculated from scenario runs with snowcoaches converted to equivalent-emission numbers of snowmobiles. 2-stroke (non_BAT) snowmobiles (thick gray line) are shown for comparison.

NOx concentrations

NOx measurements were made at Lake Village near the ranger station over a 3-day holiday weekend in 2003 . Daytime NO_2 concentrations were elevated from 9am to 5pm which corresponds to the OSV traffic period. Since there were mostly 2-stroke engine snowmobiles at that time, the NOx would have been predominately from snowcoach 4-stroke engines, Longer-term measurements of NOx have now been made at the West Entrance and at Old Faithful. Although 5-10 minute averages of NOx go over 100 ppb, the hourly averages were less than 60 ppb for the portions of winter 2009-2010 and 2010-2011 when measurements were taken (Ray, 2010).

Continuous roadside NOx (sum of NO + NO_2) measurements were made at the Yellowstone West Entrance during the winter of 2009-2010 (Ray, 2010) to determine NO_2 concentrations in relation to the new NO_2 NAAQS. The previous NO_2 NAAQS was an annual standard whereas the new standard is based on maximum daily 1-hour concentrations. The NO_2 standard is 100 ppb (see EPA, 2010) and requires 3 years of valid data. Two different NOx analyzers were used during the winter study; the first analyzer barely passed audit and calibration checks; the second analyzer was new and performed well. Table 2-9 has the NO_2 concentrations for the President's day weekend through the end of the winter OSV season. Although NO_2 concentrations of >50% of the NAAQS were observed with the first analyzer, the more reliable values are from the replacement analyzer with NO_2 up to 26% of the health standard (Ray, 2010). NO_2 concentrations during the low traffic spring period and into the summer wheeled traffic period were about 15% of the standard. Early winter NO_2 data for winter 2010-2011 has a daily maximum hourly concentration of 31 ppb. NO concentrations have been noted to be a higher proportion of measured NOx, which indicates fresh emissions. During summer when ozone is present, the reaction of NO with ozone to form NO_2 is rapid. It appears that the transport time from emission to sampling at the side of the road at the West Entrance does not provide enough time for complete conversion to NO_2 in winter.

Table 2-9. Summary of NO_2 concentrations for mid-February to mid-March, 2010.
West Entrance

Winter	Max Daily (1-hr)	90th percentile	**% of Std**	**Average**	**2nd max daily 1-hr**
Winter [1] 09-10	26	5	26%	2.1	18
Spring	14	4	14%	1.5	NA
Summer[2]	16	4	16%	1.8	NA
Winter[3] 10-11	31	NA	31%	3.2	26

1. Covers period Feb. 12 to Mar. 15, 2010 only
2. For May through July, 2010.
3. For period Dec15, 2010 to Jan. 23, 2011 only.

Some limited measurements of NOx have been made by other studies within Yellowstone during the winter season (Spear and Stephenson, 2005; Morris and Gauthier, 2005; Jensen and Meyer, 2006; Sive et al, 2003). Personal exposure measurements of NO_2 concentrations at the west entrance over holiday weekends provide some indication of what might be expected. These studies did not use EPA certified analyzers and did not collect continuous hourly data, so the values should just be taken as indicators. At the kiosks in winter 2005, NO_2 was measured up to 98 ppb while summer concentrations were found at 11 and 36 ppb (Jensen and Meyer, 2006).

Table 2-10. NOx concentrations observed at the west entrance from personal exposure studies over holiday weekends. Units are ppm.

		Winter 2005	Summer 2005	Winter 2006	Summer 2006
Nitrogen dioxide	NO_2	<0.098	0.036	- -	0.011
Nitric oxide	NO	<0.071	0.144	- -	- -

Note: ppb = ppm/1000

The emissions of NOx were estimated during scenario modeling (ARS, 2006) for the EIS in 2006 at 16 tons per year (tpy) for the then current traffic levels. This was estimated to be an increase from 9 tpy from the period when 2-stroke snowmobiles were used prior to 2003. The increase in NOx emissions was verified by dynamometer measurements and field measurements (Bishop, 2006; Bishop, 2009; SwRI, 2002) (see Table 2-6). The then current OSV use level was modeled for worst case conditions at the West Entrance to have a CO 1-hr concentration of 3.7 ppm (8-hr of 1.2 ppm). The observed maximum 1-hr concentration at the West Entrance for winter 2005-2006 was 2.1 ppm and for 2006-2007 it was 3.7 ppm (Ray, 2009). The modeling study did not report an estimated NO_2 concentration. Based on the ratio of emissions and the estimated CO concentration, a very high NO_2 might be estimated (approximately 0.5 ppm). Data from Jan, 2011 (Ray, 2011) indicates the strong relationship between the hourly CO concentration and the observed NOx at the West Entrance, For the current range of CO, NOx is expected to be 5 – 50 ppb when OSV traffic is present (Figure 2-9). Although short-term measurements at the West Entrance indicated NO_2 concentrations that might approach the new NO_2 standard, direct measurements in the last two winters have found NO_2 concentrations at less than 50% of the NO_2 national 1-hour standard.

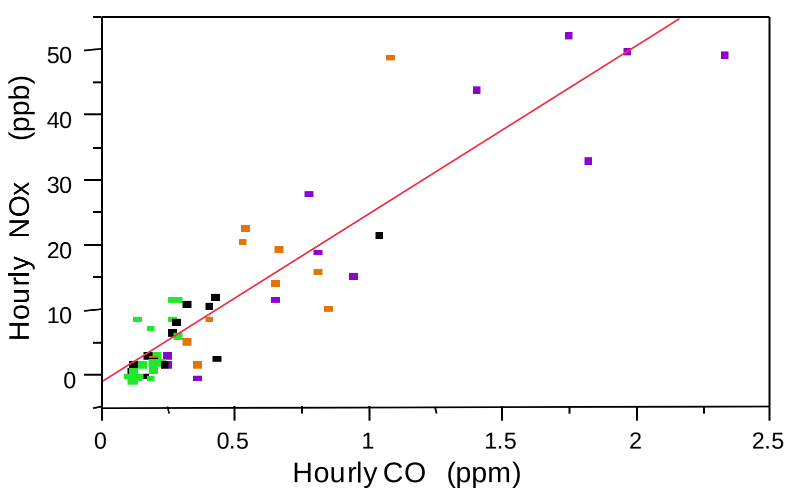

Figure 2-9. Relationship between hourly NOx and CO during morning periods at the West Entrance.

Comparison of summer and winter AQ data

Seasonal differences have been noted in air quality that is related to the type and amount of traffic, especially for CO and $PM_{2.5}$ (Ray, 2006). Between 2004 and 2005 for example, winter activity by snowmobiles and snow coaches contributed a greater amount of CO and $PM_{2.5}$ than summer traffic with wheeled vehicles, despite substantially higher numbers of vehicles in the summer than winter (Ray, 2006). Tables 2-10 and 2-11 summarize mean seasonal concentrations for different averaging periods. External influences (wildfires and dust) make total $PM_{2.5}$ more variable and with higher peaks in the summer than in the winter (Ray, 2006; Ray, 2010). CO concentrations are moderated during the summer in part due to greater vertical atmospheric mixing (Cain and Coefield, 2001; Ray, 2006; Sive, 2002). In addition, emissions from on-road vehicles have regulatory emission limits that are lower than the emissions from OSVs.(US EPA, 2008).

In comparing the observed winter CO concentrations at the two park locations, the shorter term 1-hr or 8-hr averages are 2-3 times lower at Old Faithful compared to the West Entrance (Table 2-12). The primary difference between the two monitoring sites is proximity of the station to the OSV traffic (Ray, 2008). At the West Entrance, the monitoring station is roughly 2 m from the edge of the road and most of the traffic is 10-20 m away. At Old Faithful, much of the active OSV travel is along entry roads 1-5 km away, many of the snowcoaches stop at Snow Lodge or the adjacent parking. The remaining traffic at Old Faithful passes the monitoring station on a curve 10-15 m away and parks about 80-100 m away. There are also diurnal wind direction changes at Old Faithful, however, the monitoring station was sited to be downwind of the OSV areas during the day.

The difference between winter and summer at the West Yellowstone town center monitoring station is larger than in the park. This is because of a larger volume of wheeled and OSV traffic, a mix of 2-stroke and 4-stroke engines, and longer periods during the day when traffic is present. There are also pollutant sources in town from building heater units and various businesses that are non-mobile sources.

Table 2-11. Comparison of West Entrance mean CO concentrations for different seasons, 2004 to 2010.

	Max. Daily 1-hr	Max. Daily 8-hr	Season average	90th percentile
Old Faithful				
Winter	1.42	0.56	0.19	0.26
Spring	0.54	0.29	0.17	0.20
Summer	0.84	0.54	0.19	0.26
Fall	0.26	0.19	0.13	0.16
West Entrance				
Winter	4.12	1.10	0.22	0.38
Spring	0.60	0.27	0.16	0.20
Summer	6.93	1.78	0.18	0.30
Fall	0.74	0.33	0.12	0.20
West Yellowstone town center				
Winter	3.45	1.13	0.26	0.43
Summer	5.92	1.56	0.19	0.32

Units are ppm

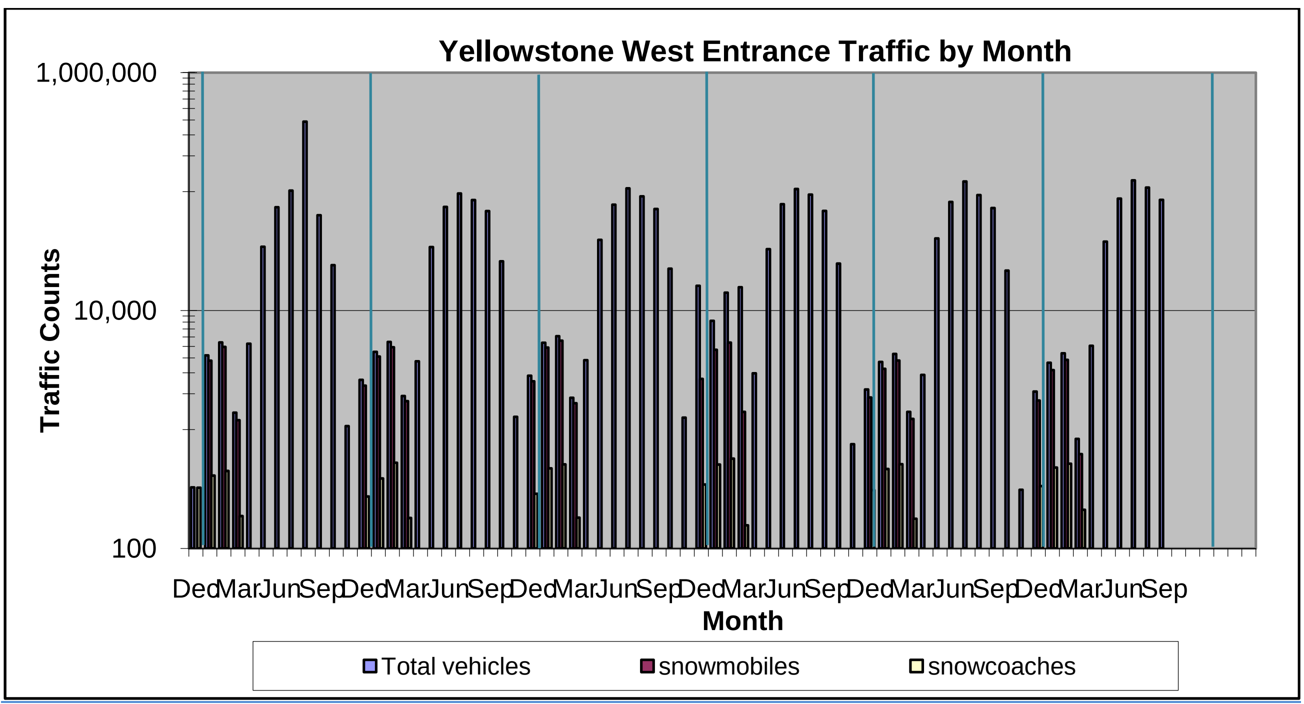

Figure 2-10. Vehicle traffic patterns by month for Yellowstone west entrance. (Note the y-axis log scale)

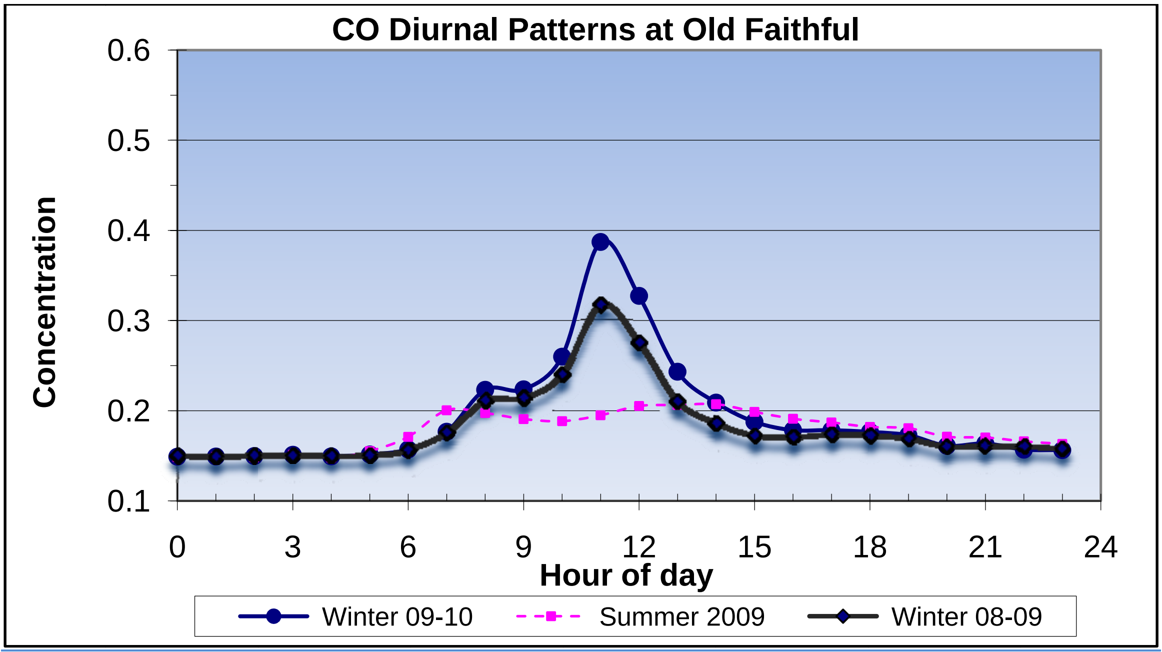

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Figure 2-11. The mean hourly CO diurnal pattern at Old Faithful peaks between 11am and noon. The wheeled traffic in summer produces a lower peak CO concentration and the daytime peak is spread out over a much longer part of the day.

Figure 2-10 illustrates the large difference in traffic through the west entrance gate between summer and winter (note the log scale for the y-axis). Despite the larger number of vehicles in summer, the CO concentration are smaller in the summer. Partly this is due to the greater vertical mixing from the higher boundary layer in the summer. The mean hourly CO concentrations (Figure 2-11) at Old Faithful show that the OSV traffic activity is more focused about the 11 am to 1 pm period, while the summer wheeled traffic is more constant during the daytime, then tails of in the evening. Overnight concentrations of CO are at nearly the regional background concentrations.

Emissions studies

There have been numerous studies to examine the emissions from 2-stroke snowmobiles, 4-stroke snowmobiles, and various snowcoaches. Table 2-6 lists the various studies and their findings. Engine testing as prescribed by EPA to relate to emission standards is done on a dynamometer. Using this technique the power, emissions, and other performance indicators can be measured very precisely. Real travel conditions can be simulated by changing the resistance and adjusting the throttle condition, if an accurate profile is available. The dynamometer tests of just the engine give a good baseline and relative performance, but do not emulate actual use in Yellowstone of the full working vehicle (Bishop, 2004).

An example of the variation in emissions from loading is given in Figure 2-12 where the average OSV emissions from the 2005 direct emissions study are given as the average per passenger emissions for a typical trip. Note how up-hill travel increases the emissions and the CO and NOx are out of phase. Additional single vehicle emission maps like this are found in Bishop, 2007. Day to day variations from weather and snow conditions are harder to obtain since emissions measurements were not repeated on OSV vehicles by the researchers. One snowcoach concessionaire did volunteer his complete fuel usage records for the season (Baily, 2006) that shows a factor of 8 variations in the amount of fuel used per trip (Figure 2-13). New snowfall alone was found to not account for the large variations. Experience by researchers in travel along the route suggests that surface grooming, total depth, snow consistence, temperature, winds, solar radiation, and congestion can all affect the mileage and emissions.

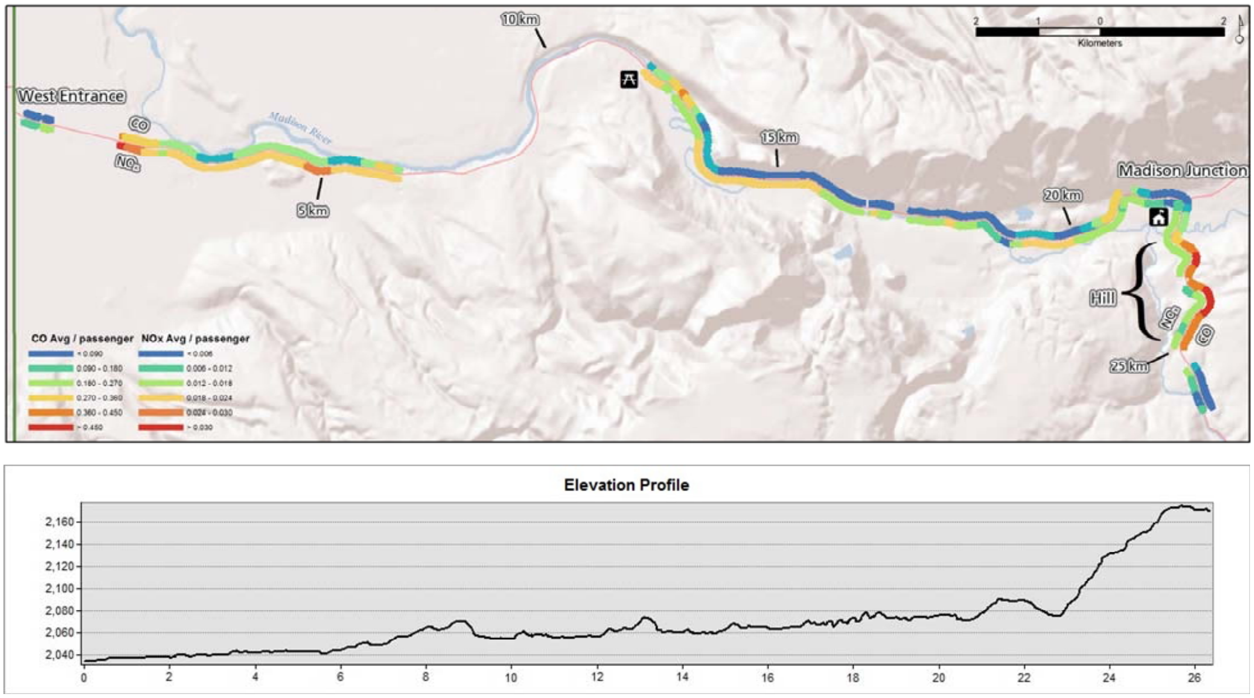

Figure 2-12. The upper graphic shows the Yellowstone NP route from the West Entrance to the turn-around point where the road meets up with the Firehole River. The color bands show the emissions of CO (upper) and NOx (lower) along the route for both snowmobiles and snowcoaches as a single traverse on a per passenger basis. The lower graph gives the change in elevation along the route. (Graphic: D. Bingham)

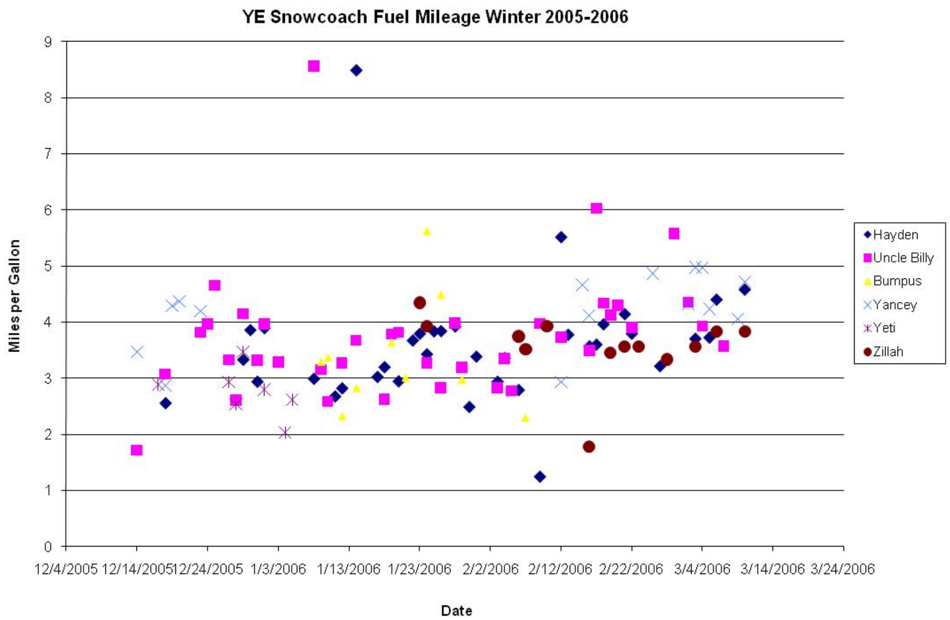

Figure 2-13. Fuel usage records for six snowcoaches used in Yellowstone during winter of 2005-2006. There are large differences in fuel usage from trip to trip over the same course from West Yellowstone to Yellowstone Falls area (Baily, 2006)

2- stroke engine emissions

Although current park regulations effectively prohibit 2-stroke engine snowmobiles, it is useful to compare the previous snowmobiles to understand why the air quality in the park has improved. Emission studies have been done on snowmobiles engines and working snowmobiles in the field (*White and Carroll*, 1998; *Carroll and White*, 1999; *Morris et al.*, 1999; *Bishop et al.*, 2001; Southwest Research Institute, 2002). Remote sensing studies were used to measure emissions from snowmobile travel through the west entrance. It was found that oxygenated fuel blends (with ethanol) could reduce CO emissions in 2-stroke snowmobiles by only 7 ±4%, but the oxygenated fuels had little effect on hydrocarbon emissions (Bishop et al., 2001). Toluene was measured in 2-stroke snowmobile exhaust at 1,976 ppm (Morris et al., 1999).

Results from the Sive et al., 2003 study indicate higher emission levels for the 2-stroke snowmobiles are roughly 2-20 times greater than for 4-stroke snowmobiles or snowcoaches, and significantly larger than those of the diesel snow-cat. Additionally, the 2-stroke engine types emitted much larger quantities of air toxics (i.e., benzene, and toluene) than the other engine types. See Figure 2-14 for a comparison of hydrocarbon emissions.

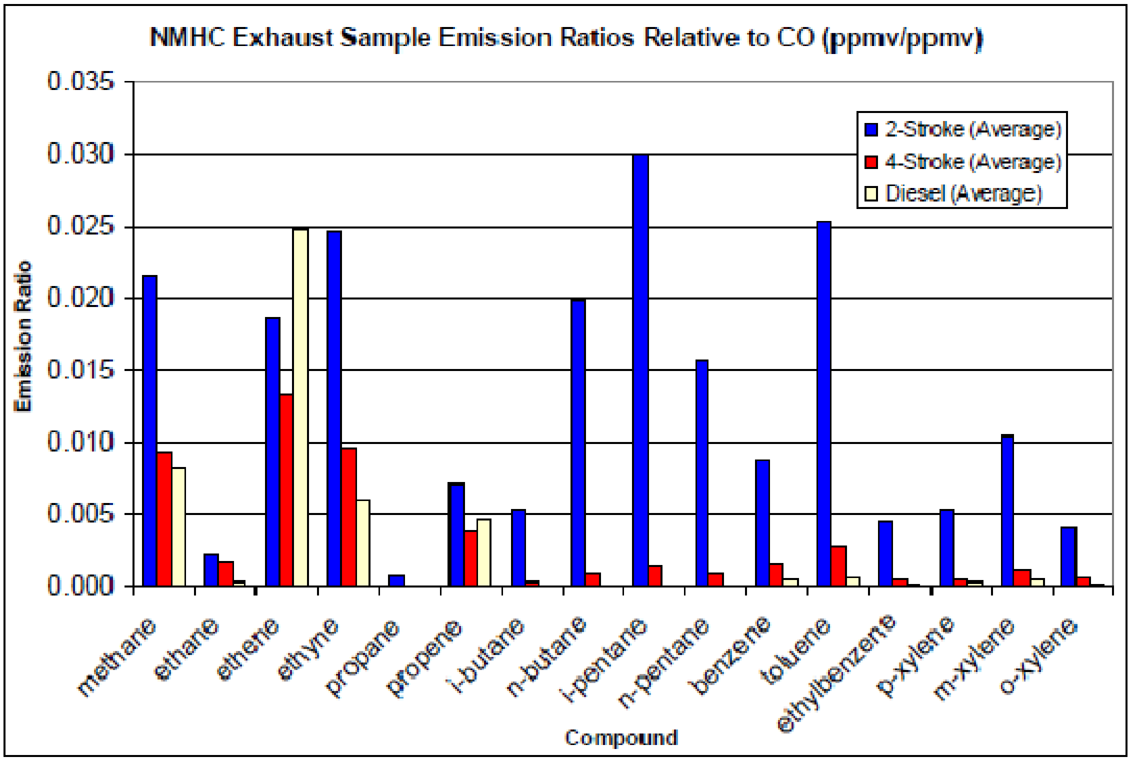

Figure 2-14. Average NMHC exhaust emission ratios relative to CO (ppmv/ppmv) for 2-stroke (blue bars) versus 4-stroke (red bars) snowmobiles engines and diesel snowcoach engine (white bars). The benzene, toluene, xylenes emissions from 2-stroke snowmobiles are much higher.

4-stroke engine emissions

The relative contribution of snowmobiles and snow coaches to air quality degradation has been examined in a recent follow-up study (Bishop et al. 2009), which found that 4-stroke snowmobiles and snowcoaches contribute approximately equal per-passenger emissions. Studies were conducted by Bishop et al. (2007) in which data were collected for more than 34 hours and 500 miles of emissions from nine snowcoaches and more than 960 snowmobiles. The study found that both four-stroke snowmobiles and even non-BAT-equipped snowcoaches have lower emissions per person than the two-stroke snowmobiles. In a follow-up study (Bishop et al. 2009), in which tailpipe data were collected from mostly newer technology snowcoaches and two four-stroke snowmobiles, these two primary winter vehicle types were found to be very similar in per-passenger emissions. In addition to their already near-equivalent emissions per passenger compared to BAT equipped snowmobiles, snowcoach emissions generally decrease with decreasing vehicle age and the use of updated fuel- injection technology. Carbureted engines produce more excess emissions than throttle-body-injected engines, which produce greater emissions than port fuel injected engines (see Figure 2-15). Another important finding of the 2009 study was that despite the use of standardized route and passenger loading, road and snow conditions can contribute to large increases in CO and HC emissions regardless of the type of vehicle (See Figure 2-12). As a result of computer-controlled fuel-injection engines, snowmobiles were also found to have better fuel economy than previously estimated (>25 mpg).

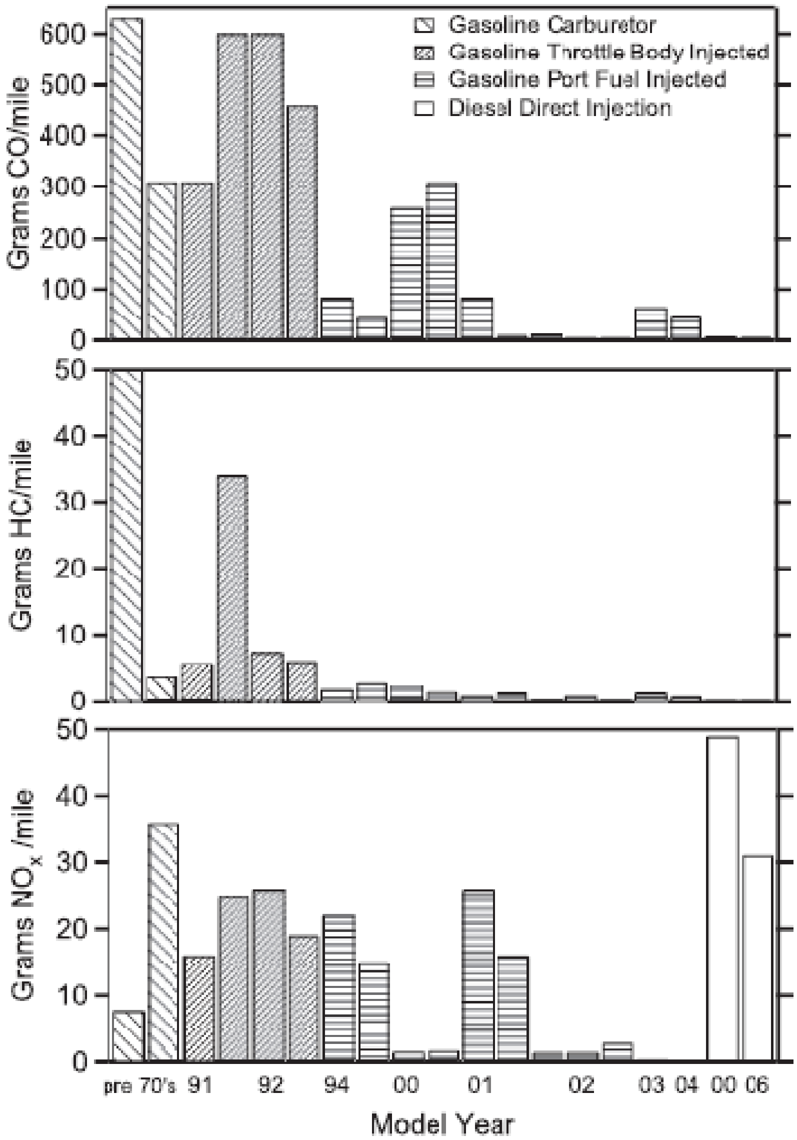

Figure 2-15. Combined snowcoach measured emissions comparison arranged by year and fuel and fuel management technology for (a) CO, (b) HC, and (c) NOx emissions. Within each technology class, the vehicles are ordered left to right by model year. (HC emissions were not collected on the diesel snowcoaches.) (Bishop et al., 2009)

In one very short 2009 study, the relative contributions to air pollution levels at the entrance station, was measured by separating snowmobiles and snowcoaches into different lanes (Radtke, 2009). There were 241 snowmobiles and 19 snowcoaches in this study. Most pollutants tested were similar in concentration. Average CO concentrations were higher in the snowmobile lane, but peak CO concentrations were slightly higher in the snowcoach lane. Hydrocarbon samples were below detection limits. This was a one day study with adjoining entry lanes. There was not enough difference to make a definitive statement.

2.3.2 Transport of emissions from outside the park into YNP

Spatial pollutant studies

Air pollutant measurements have generally been made at only a few locations within the park, usually near the roadways. The spatial extent of elevated pollutant concentrations and the total area affected is not well known. Air pollutants are subject to rapid dilution both vertically and horizontally; a process dependent on winds, temperature, solar radiation, and other environmental factors. Spatial concentration studies were conducted by Sive et al, 2003 during two winter periods prior to the implementation of the snowmobile BAT requirement. The researchers found that hydrocarbons were greatly diminished 500 m from the road compared to 50 m downwind of the road by approximately 80% for toxic aromatics (Sive et al., 2003; Yong et al, 2009). The CO concentration decreased by 50% to CO background concentrations at 500 m. The researcher's conclusion that the differences with distance from the road was not statistically significant was partly a reflection of the small number of samples and their inclusion of both AM and PM samples when only the PM samples were affected by OSV traffic.

The Sive et al, 2003 spatial study found high concentrations of organics over a broad area of western Yellowstone that were well above the expected background concentrations (Table 2-12). High hydrocarbon concentrations, specifically the toxic aromatics, were found on the road segments between the west entrance and Old Faithful quite often. The road segment in the north end of the park that is open to wheeled traffic had a different profile and lower concentrations. Neither a consistent nor a persistent gradient along park roads was found from the multiple location study. Hydrocarbon concentrations returned to near back ground levels overnight for most locations, the notable exception being near the west entrance.

Table 2-12. Comparison of aromatic organic HAPS in Yellowstone to expected background (Sive et al., 2003)

	Benzene	**Toluene**	**Xylenes**	**Ethylbenzene**	**units**
background	0.1	0.04	0.005	0.005	ppbv
peak 2002	4.82	9.89	5.92	0.99	ppbv

The Sive et al. study is consistent with roadside measurements elsewhere that show that mobile source air pollutant concentrations drop off rapidly with distance from the road (Durant et al., 2010; Beckerman et al, 2008; Zhu et al., 2002; Roorda-Knape et al., 1998). Downwind from a road NOx, VOC, CO_2, and particulates were all found to approach the area background within 300 – 500 m; upwind concentrations were at area background by about 50 m from the road. Higher wind speeds typically lead to more rapid dilution and a shorter distance from the road affected by elevated concentrations. Changes in mixing height and wind speed during the day make the affected downwind areas variable (Durant et al., 2010). These general observations are thought to apply also to the Yellowstone road corridors. From Figure 2-12 it can be seen that the OSV emissions for CO and NOx are not the same for all road segments.

Regional emissions and transport

Evening and overnight concentrations have been observed at the west entrance during periods when no traffic is on the park road. Concentration data from the West Yellowstone city center monitor and wind direction suggest the observed elevated concentrations of $PM_{2.5}$and CO are being transported from the town into the park (Ray, 2007). Localized park emissions from non-mobile sources have also been observed at Old Faithful (Ray, 2007) for CO and PM2.5 and at Lake Village for hydrocarbons and NOx. Wheeled on-road traffic on the northern in-park road segments have been shown to have increased hydrocarbon concentrations (Sive et al, 2003). Transport of some hydrocarbons from outside the park was shown by a detailed analysis of alkyl nitrates, however, daytime hydrocarbons were shown to be mostly of recent origin and strongly related the emissions from OSVs (Sive, et al., 2003; Zhou et al., 2010).

Monitoring at Flagg Ranch

Monitoring at Flagg ranch staging area just south of the park entrance was done in winter of 2002-2003, prior to BAT and guiding. Ambient concentrations of CO and $PM_{2.5}$ were slightly larger than at Old Faithful. The second highest CO concentration was 3.1 ppm and highest $PM_{2.5}$ was 16 ug/m3 compared to 31. ppm and 9 ug/m3 at Old Faithful. At this location snowmobiles were unloaded in a parking lot and often left idling to warm up. Groups left in the morning and there was low activity until the snowmobiles returned in the late afternoon. Monitoring by the state of WY at a location farther from the road and parking lot found CO was close to the regional background (WY DEQ, 2003).

2.3.3 Health concerns

Entrance HAPS studies

In addition to air quality in the park, personal exposure to higher concentrations of pollutants at entrance stations have been found. Measurements (Spear and Stephenson, 2005; Morris and Gauthier, 2005; Jensen and Meyer, 2006) at entrance stations were taken over several winters and summer periods to evaluate exposure to several air pollutants; including CO, VOCs, particulate matter, and aldehydes. Even in 1997, when park entrance station staff was exposed to substantially greater amounts, CO exposure was not found to be above workplace health standards set by Occupational Safety and Health Administration (OSHA) (Radtke, 2007). This finding was largely upheld in subsequent studies; those studies conducted after a requirement for BAT on snowmobiles found concentrations of all airborne contaminants measured to be well below current standards.

A 2000 OSHA study at the west entrance concluded that personal exposures to toxics were below OSHA PEL and AGGIH TLVs but that entrance employees were exposure to benzene, formaldehyde, and carbon monoxide that exceeded the NIOSH RELs (OSHA, 2000). A 2004 study at the west entrance, Madison warming hut, Mammoth mechanic shop, and the Old Faithful ranger station came to similar conclusions that occupational exposures were well below the standards (Bowers, 2004). A winter study in 2005 concluded that occupational exposures to airborne toxics were significant less than exposures in previous studies. It was observed that no long lines of snowmobiles waited to pass through the entrance gate and that snowmobile guides and snowcoach drivers often turned off their engines while at the kiosk. Integrated samples for aldehydes, BTEX compounds, and $PM_{4.0}$ were below detection limits. The air intake systems to the kiosks were judged to be an important factor at keeping the kiosks under positive pressure and achieving an air exchange of once per minute even with the window open 30 inches Spear and Stephenson, 2005)

A 2006 occupational exposure study (Jensen and Meyer, 2006) at the west entrance found CO, BTEX, elemental carbon, $PM_{2.5}$, NO_2, VOCs, and aldehyde all to be below standards and most below detection limits. Peak CO at 546 ppm exceeded the NIOSH ceiling of 200 ppm on one day. Short term exposures (STEL) of CO were in the 2-5 ppm range. NO_2 concentrations measured inside the kiosk ranged from 6-13 ppb. In the previous summer of 2005 a personal exposure study was conducted to compare conditions when wheeled traffic was entering the west gate (Morris and Gauthier, 2005). Once again the concentrations measured inside the kiosks were well below the occupational health standards. The mix of vehicles and engines was very different than in winter with a higher proportion of diesel engines. Motorcycles and older vehicles were noted to sometimes produce higher pollutant concentrations. On busy days, four times as many vehicles entered through the west gate as during the winter.

On snowmobile HAPS studies

Park visitors either on snowmobiles or as passengers in the snowcoaches are more likely to be exposed to toxic aromatic organics such a BTEX or aledehydes than the park employees at the kiosks. Their exposure is likewise going to be longer as they travel along the park roads. Direct personal exposure measurements were made by Kado and Kuzmicky, 2001 for 2-stroke snowmobile travel.

Hydrocarbons are volatile organic compounds that include benzene, toluene, ethylbenzene, and xylenes. Kado et al. (2001) found high levels of exposure of benzene for various employees in YNP. They found that workers at the West Entrance were exposed to benzene concentrations of 100 to 300 µg/m3, mobile patrol employees 100 to 200 µg/m3, and a mechanic working indoors 500 µg/m3. The mechanic level of exposure exceeded the National Institute for Occupational Safety and Health recommended exposure level for benzene (320 µg/m3). While these compounds can cause dizziness, headaches, and loss of consciousness, the EPA has also identified benzene as a carcinogen, and those exposed to benzene have an increased incidence of leukemia.

Carbon Monoxide (CO)

Snook Fussell (1997) quantified carbon monoxide releases with 2-stroke snowmobiles in Grand Teton National Park and concluded that tourists are exposed to significant and dangerous levels of CO. This is compounded by the fact that most tourists travel in large groups (eight on average, Littlejohn 1996), snowmobile trails force travel directly behind other snowmobiles, most trails are at high elevation (increasing susceptibility to adverse effects), and many trips require several hours of driving. CO binds to the hemoglobin in blood and inhibits the transportation of oxygen in the body. High levels of CO exposure have been shown to lead to visual impairment, reduced work capacity and mental dexterity, poor learning, nausea, headaches, dizziness, and even death (EPA 1991).

Particulate Matter (PM)

Particulate matter, also found in snowmobile emissions, is detrimental in fine and coarse forms as it accumulates in the respiratory system and can lead to decreased lung function, respiratory disease and even death (Janssen and Schettler 2003). Of the pollutants emitted by snowmobiles, particulates are of special concern because their small size makes them easily respirable and thus delivered directly into the lungs, causing any number of the aforementioned maladies (NPS 2000).

2.4 Conclusions

- Air pollution related to winter OSVs at the park has primarily been problematic at congested locations such as the entrance stations, rest areas, thermal feature parking lots, and at Old Faithful. Measurements have shown that pollutant concentrations drop off rapidly with distance from the road and that air quality generally improves to near regional concentrations overnight Ray, 2008; Sive, 2003; Zhou, 2010).

- The air quality condition for CO and $PM_{2.5}$ attributable to OSV traffic is currently well below the federal air quality standards at the congested areas near the west entrance and

Old Faithful. Air quality conditions along most of the road segments are expected to be similar to the Old Faithful concentrations. At distances beyond 300-500 m from the roads, concentrations of CO, $PM_{2.5}$, and organics should approach background concentrations.

- NO_2 concentrations have been measured at concentrations at 20-80% of the standard by continuous monitors and for short periods at concentrations above 0.1 ppm. The NO_2 may be of more concern than CO or $PM_{2.5}$ at this point. 4-stroke engines and diesel engines have higher NOx emissions than 2-stroke snowmobiles.

- Winter activity by snowmobiles and snowcoaches contributes a greater amount of carbon monoxide than summer traffic, due to higher emissions from OSVs than cars and atmospheric conditions that inhibit the dispersal of emissions. Emission contributions from the current mix of BAT snowmobiles and unregulated snowcoaches is about equal. Even lower emission levels from modified production snowmobiles has been demonstrated in the Clean Snowmobile Challenge. Cleaner emitting snowcoaches than the present vehicles being used in the park have been demonstrated by the Bombardier snowcoaches outfitted with modern engines with pollutant controls and catalytic converters. A BAT for snowcoaches should be possible and would lead to a reduction in emissions.

- Spatial distribution studies indicate that the highest concentrations of air toxics, CO, and $PM_{2.5}$ are at congestion points and that concentrations drop rapidly with distance from the road. There are indications from the monitoring data that CO and $PM_{2.5}$is transported into the park from West Yellowstone during evening and night time hours when there is no OSV traffic on park roads. This probably occurs during the day also when winds are from the west. The West Yellowstone city center monitoring station records much higher CO and $PM_{2.5}$ concentrations during the day and concentrations persist late into the night. When winds blow towards the park entrance area, CO and $PM_{2.5}$ are observed at night even though there is no traffic on the entrance road.

- Personal exposure studies of air toxics have generally not found concentrations near the OSHA standards. The positive pressure ventilation system to the kiosks does a good job of maintaining clear air when the window is opened only briefly. If excessive idling is avoided and the entrance kiosks and the ventilation systems are working correctly, park employee exposure to air pollutants is below occupational standards.

- OSV management changes have been effective in reducing ambient air pollutants at the West Entrance and Old Faithful. The reduction in CO and $PM_{2.5}$ concentrations is due to lower numbers of OSVs, cleaner emissions from the BAT requirement, and changes in gate procedures that reduce the number of OSVs that are at the entrance.

- Some air toxics and hydrocarbons are being deposited near the road, but concentrations in the melt water are small. Some increased ammonium was observed in the snowpack close to the roads when 2-stroke snowmobiles were dominate, but those concentrations have decreased. Nitrate concentrations in the snow are low. Deposition from OSV emissions appears to drop off rapidly from the road edge and to be minor for distances of more than 300 m.

- Snowcoach emissions are a substantial part of the total. A BAT requirement that would limit the number of high emitted snowcoaches would have a positive effect on air quality along the roads and at congestion points. Administrative use of OSVs have become a larger percentage of traffic as the number of snowmobiles entering the park have decreased. The current administrative contribution to emissions and air quality is about 10%.

- The fate of OSV-specific pollutants within Yellowstone National Park has not been fully characterized, but we may infer from what data are available that most potential ecosystem effects from OSV are negligible.

- No effect of OSV-emitted CO is expected on wildlife or vegetation at the atmospheric levels recorded in Yellowstone National Park (less than 3 ppm; Ray, 2010). While wildlife chronic exposure to CO has not been evaluated, we can infer from laboratory studies on animals and humans that the lowest effect levels require ambient concentrations to be much higher.

- Based on general knowledge and understanding of nitrogen sources and effects in the Western United States, additional inputs of nitrogen (as NO_3^- or NH_4^+) from OSV could be important to assess. The nitrogen emissions of OSV should be considered in the context of the background deposition levels.

- Buffered snow as is found in Yellowstone National Park would likely not affect soil acid status and that any potential OSV effects on chemical composition of soils would be imperceptible in part due to the geothermal and fire regimes within Yellowstone. The natural patterns of disturbance (such as fire, grazing and drought) likely mask any changes in soil nitrogen status from total (not just OSV) atmospheric deposition. Because the groomed snow road overlays the main summer road, soil health issues from compaction or erosion are not expected at Yellowstone National Park as a result of OSV use.

- Biota have adapted to specific hydrogeochemical conditions, some of which would be considered toxic or impaired anywhere else. Given these conditions it is unlikely that current OSV emissions would have a distinguishable effect.

- Generally, likely sinks for VOC in snow would be VOC in spring runoff and potentially some soil infiltration. Snowmelt data from 2003-2004 indicated VOC concentrations were low and did not exceed EPA standards for surface water and well below levels that would adversely impact aquatic systems.

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2.6 Appendix

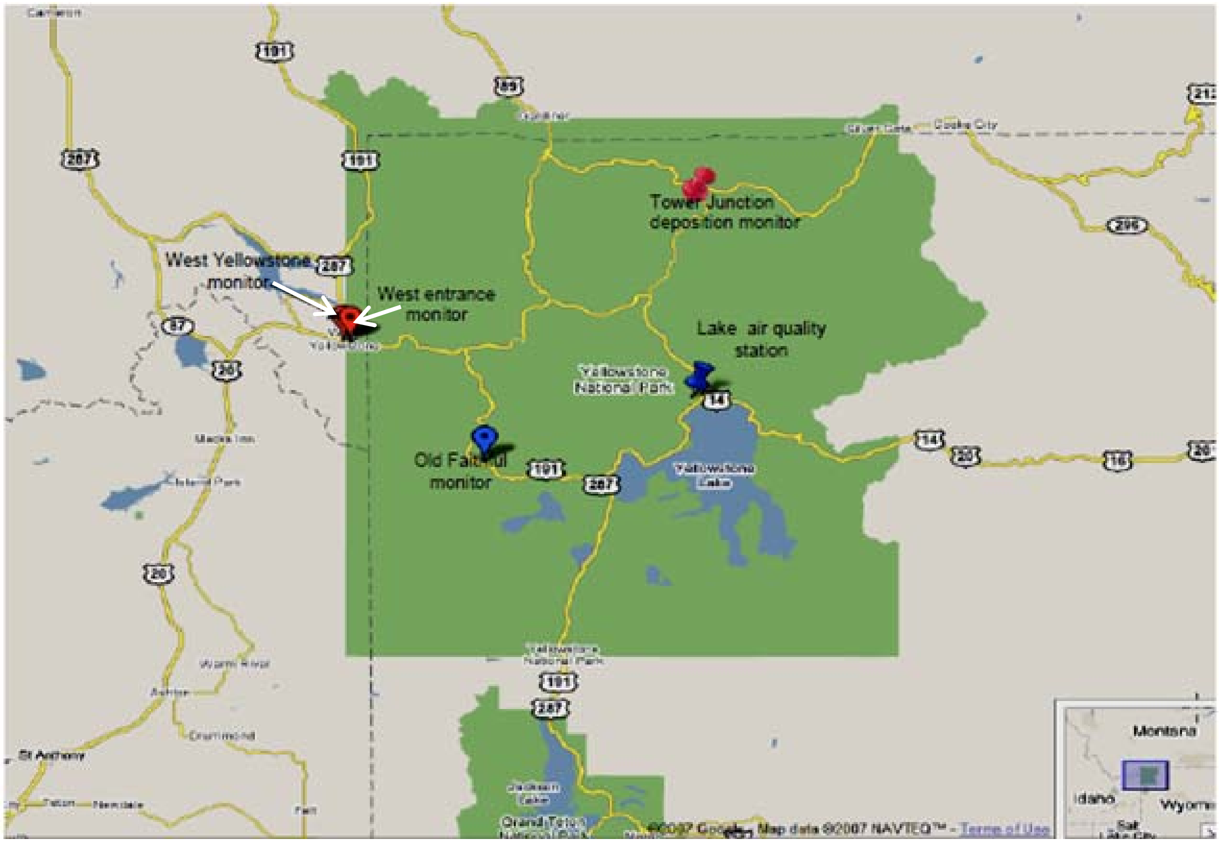

Figure A-1. Map of Yellowstone National Park with the air quality monitoring sites marked.

3. Acoustic Resources

3.1 Introduction

“Noise” and “sound” are often used as synonyms in casual conversation. However, noise is properly defined as unwanted or extraneous sound (Morfey 2000). This definition encompasses a subjective or perceptual judgment (unwanted) and an objective classification (extraneous). Transportation noise merits its designation because the sound produced is not intrinsic to the activity; it is a byproduct. In contrast, sonar signals used to detect submarines or music broadcast from a portable stereo may be noise or not, depending upon the receptor. The loud calls of a native cicada species may be regarded as noise by a park visitor, but they represent a park resource for NPS. Perceptual judgments play a role in managing visitor experience, but for acoustic resources the critical determination is whether the sound is extraneous to the resources the park was established to protect.

In National Park units, noise affects visitor experience, wildlife, and the physical resource itself (the acoustical environment). Barber et al. (2010) summarize the diverse literature documenting the effects of noise on wildlife; the issue is treated at length in the wildlife section of this report. The varied impacts of noise on visitor experience are also treated in a separate chapter. This chapter addresses the NPS requirement to protect the acoustical environment or soundscape resources themselves (NPS 2006, 4.9). The Natural Sounds and Night Skies Division recommends restricting the term soundscape to apply to the totality of the perceived acoustical environment (NPS in litt.). A definition very like this is being codified by an International Standards Organization working group (ISO in litt.). Accordingly, this chapter will refer to acoustic resources or the acoustical environment because it addresses the physical resources. Discussions of the impacts of noise on the human soundscape – both objective and subjective measures of effects – are treated in the chapter addressing visitor experience.

3.2 Noise

Noise is a significant and proliferating environmental problem. Since 1973, the Department of Housing and Urban Development (HUD) has conducted an Annual Housing Survey for the

Census Bureau. Noise has consistently ranked as a leading cause of neighborhood dissatisfaction, with nearly one-half of the respondents reported that noise was a major neighborhood problem (EPA 1981). Over 40 percent of the U. S. population is exposed to transport noise levels exceeding L_{Aeq} – the average, A-weighted sound level – of 55 dB (OEDC, 1993), the level that the U. S. Environmental Protection Agency (EPA 1974) and the World Health Organization (WHO 1999) believe should not be exceeded in order to protect human health and welfare. Noise growth is outpacing population growth. The U. S. population increased by approximately one-third between 1970 and 2007 (U. S. Census in litt.) yet traffic on US roads nearly tripled, to almost 5 trillion vehicle kilometers per year (U. S. DOT in litt.). Aircraft traffic is growing faster, tripling over the years from 1981 to 2007 (U. S. BMT in litt.).

Noise impact analyses became common in the U. S. following the passage of the Noise Control Act of 1972 (Pub. Law 92-574) and the Quiet Communities Act of 1978 (Pub. Law 95-601). The U. S. National Research Council published guidelines for preparing environmental impact statements on noise in 1977 (NAS 1977). This guidance focuses entirely on noise impacts in communities. As discussed in the section addressing standards below, many established noise impact criteria are inappropriate for National Park settings and resources. For example, the National Research Council guidance (ibid) suggests that an outdoor L_{Aeq} level of 60 dB offers an acceptable acoustical environment for parks; recent research has shown that increased risk of hypertension, heart attack and stroke begin to appear at this noise level (Babisch 2006, 2008, Sorensen et al. 2011).

3.3 Acoustical Metrics for Community Noise

Sound is characterized by several properties; fundamental examples are intensity (perceived as loudness), frequency (perceive as pitch), and duration. Sound is an inherently dynamic phenomenon: minute fluctuations of air pressure. The reference pressure level for atmospheric sound is 20 μPa (microPascals); this 0 dB level approximates the human threshold of hearing (Crocker 1997). Intense sounds exceeding 120 dB begin to cause pain. 120 dB – or 20 Pa – corresponds to pressure changes equivalent to a 1.7 meter change in altitude. The threshold of human hearing corresponds to pressure changes equivalent to a 1.7 micron change in altitude (www.engineeringtoolbox.com).

Sound represents pressure fluctuations. Humans do not begin to perceive pressure fluctuations as sound until they are repeated at least 20 times per second (20 Hz); this is why we do not hurt our ears when we climb a flight of stairs. Frequency measurements used to be specified in cycles per second (cps), but this unit has now been designated as the Hertz (Hz). The nominal range of human hearing – the audible spectrum – spans from 20 Hz to 20 kHz.

The enormous dynamic range of sounds and human hearing encouraged the use of logarithms. Logarithmic values also simplify some estimates of sound propagation. The logarithmic unit of measure is the deciBel (dB), named after Alexander Graham Bell. A decibel is $10*\log10(L/L_0)$, where L_0 is the reference sound level. Every increase of 10 dB represents a tenfold increase in sound level. Thus, a 20 dB signal relative to 20 μPa has a sound level 100 times higher than is required for humans to perceive it.

Although instantaneous measurements of pressure deviation are sometimes used – for explosions and other impulsive sounds – sound level is usually calculated as the average of the squared pressure deviations. This measurement is designated L_{eq}, denoting the integral of the squared pressure deviations divided by the interval of measurement. L_{eq} is proportional to the average acoustical energy (Crocker 1997).

Both the National Research Council (NAS 1977) and the World Health Organization (WHO 1999) recommend using L_{Aeq} to evaluate impacts from noise. The capital "A" in this notation indicates the use of A-weighting to integrate sound energy across all frequencies in the audible spectrum. A-weighting is based on an approximate evaluation of equal perceived loudness across the audible spectrum. Humans hearing is most sensitive between 1 kHz and 6 kHz (Crocker 1997), with significant decreases in sensitivity below and above these frequencies. A-weighting seeks to account for this differential sensitivity, to yield a aggregate measure of sound level across all frequencies. Many documents refer to sound levels in units of dBA or dB(A). In almost all cases, this shorthand notation refers to L_{Aeq}.

L_{Aeq} is sometimes annotated to include the interval of measurement. Standard NPS monitoring protocols utilize $L_{Aeq,1s}$, standard Federal Highways noise assessments use $L_{Aeq,1h}$, and standard evaluations of community noise use a specialized form of $LA_{eq,24h}$ called L_{dn}. L_{dn} adds 10 dB to the sound levels measured between 2000 and 0600 hours before computing the 24 hour average. This intends to account for greater human sensitivity to noises at night.

The NPS utilizes the percent time that noise is audible to characterize impacts to soundscapes. In field monitoring, these data are collected by a person with healthy hearing who listens attentively and notes the time, duration, and identity of all perceptible sounds. In sound modeling, audibility is computed by comparing the 1/3rd octave spectrum of the incoming noise level against the 1/3rd octave spectrum of the natural background sound level (Fidell et al. 1979). Detectability in each band is calculated as the product of three terms: the signal-to-noise ratio in each 1/3rd octave band, the square root of the bandwidth for the band, and the efficiency of human detection in this band. Overall detectability is calculated as the Euclidean distance of the aggregate of these band values from zero. In current models, a signal is audible when 10*log10(overall detectability) > 7 dB (Ikelheimer and Plotkin 2004).

3.4 NPS Management Policy on Acoustic Resources

The National Park Service evaluates noise impacts from a unique perspective that derives from the Organic Act and subsequent foundational legislation. The Service is to conserve park resources unimpaired for the enjoyment of future generations. The National Park System General Authorities Act of 1970 (Pub. Law 91-383) described National Park units using terms like "superlative natural, historic, and recreation areas" and "superb environmental quality." This language establishes very high standards for acoustic resource management. This Acoustics Chapter exists because the NPS Management Policies (2006, 4.9) interpret this mandate as follows:

> Park natural soundscape resources encompass all the natural sounds that occur in parks, including the physical capacity for transmitting those natural sounds and the interrelationships among park natural sounds of different frequencies and volumes.
>
> The Service will take action to prevent or minimize all noise that through frequency, magnitude, or duration adversely affects the natural soundscape or other park resources or values, or that exceeds levels that have been identified through

monitoring as being acceptable to or appropriate for visitor uses at the sites being monitored.

Usage of the term soundscape is evolving, and the definition emerging from international standards meetings differs from NPS Management Policies by excluding physical resources and focuses on human perception of those resources.

The requirement to prevent or minimize adverse effects to the physical resource itself – the acoustical environment – is an evolving practice. Most of the foundational work is taking place in the NPS Natural Sounds and Night Skies Division and a few National Park units that have active acoustical monitoring and research programs (Selleck 2010). This requirement is not contingent upon visitor sentiments regarding the appropriateness of sound sources. Any sounds that are not intrinsic to the resources that the park was founded to conserve are subject to management to minimize their impacts on the acoustical environment.

Congress specified a management standard for acoustical environments in the Grand Canyon Enlargement Act of 1975. The Act recognized "natural quiet" as a resource or value to be conserved. This language was reinforce in the National Parks Overflights Act of 1987, which required the restoration of natural quiet at Grand Canyon and required the NPS to present a report analyzing the nature, scope, and effects of scenic tour overflights of all National Park units. The ensuing Report to Congress (NPS 1994) defined "substantial restoration of natural quiet" in terms of the percent of the day in which aircraft sounds were audible. Percent time audible (or "audibility") has been utilized by every subsequent NPS acoustical analysis.

3.5 The Relevance of National or International Standards

National Technology Transfer and Advancement Act of 1995 and OMB Circular A-119 establishes policies on Federal use and development of voluntary consensus standards. All federal agencies must use voluntary consensus standards in lieu of government-unique standards in their procurement and regulatory activities, except where inconsistent with law or otherwise impractical. However, this policy does not preempt or restrict agencies' authorities and responsibilities to make regulatory decisions authorized by statute.

Noise exposures in National Park units will approach limits identified by the U. S. EPA and other agencies in exceptional circumstances, as in the immediate proximity of motorized vehicle corridors or building ventilation equipment. Conservation of “superlative natural, historic, and recreation areas” and “superb environmental quality” is plainly incompatible with noise exposures that can cause hearing loss, hypertension and heart disease, and strokes. The U. S. Occupational Safety and Health Administration (OSHA) requires hearing protection for employees exposed to more than 85 dB $L_{Aeq,8h}$ (OSHA in litt.). L_{Aeq} or the equivalent sound level is the integral of the sound energy over an interval divided by the length of that interval. It is interpreted as the steady-state sound level that would produce the same total exposure as the fluctuating levels that was observed. The U. S. Environmental Protection Agency determined that outdoor noise levels should be limited to less than 55 dB L_{dn} to adequately protect against interference with outdoor activities or annoyance (EPA 1974). L_{dn} is a 24 hour L_{Aeq} with 10 dB added to sound energy levels between 2200 and 0600 hours. Subsequent EPA land use guidance (1980) indicated that 55 dB L_{dn} was the most protective criterion, and applied this to parks, nature exhibits, and recreational activities. This document also designated areas exposed to L_{dn} of 65 dB as compatible with residential housing, noting that this reflected “individual Federal agencies' consideration of general cost and feasibility factors as well as past community experiences and program objectives. Localities, when evaluating the application of these guidelines to specific situations, may have different concerns or goals to consider.” However, the sufficiency of these criteria to protect human health and welfare is challenged by recent studies documenting significant increases in hypertension, heart disease, and risk of stroke for noise exposure levels exceeding L_{Aeq} of 60 db (Babisch 2006, 2008, Sorensen et al. 2011).

ANSI S12.9-4 (2008) and ISO 1996-1 (2003) specify methods for predicting the percent of a population likely to be highly annoyed by noise. The 55 dB L_{dn} criterion in EPA (1980) corresponds to an urban setting in which 4.1% of the population is predicted to be highly annoyed. While this criterion may be of limited value in National Park units, these standards specify three factors that are used to adjust annoyance thresholds in communities. 10 dB should be added to the measured or predicted noise level for rural locations where quiet is an amenity and a value. 5 dB should be added for a new or unfamiliar noise source. Finally, 5 dB should be added for a tonal noise source. Accordingly, this standard predicts up to 4% of park visitors will be highly annoyed at L_{dn} of 35 dB. The standard also predicts that the percent of park visitors who will be highly annoyed will double with every 6 dB increase in noise exposure.

The above standards address maximum tolerable noise exposure in urban settings, in which the least intrusive effect is high levels of annoyance. Attention to maintaining high quality acoustical environments has focused on indoor spaces. American National Standards Institute (ANSI) Standard 2.12 specifies L_{Aeq} of 35 dB as the background level for indoor spaces where quiet and outstanding listening conditions are important (bedrooms, auditoria, theatres, conference rooms). The World Health Organization has determined that L_{Aeq} of 30 dB is the appropriate sound level in bedrooms (WHO 1999). This determination is supported by the recent findings of Haralabdis et al. (2008) that documented physiological arousal in sleeping humans to noise events exceeding L_{Amax} of 35 dB, even when they were not awakened. ANSI Standard 12.60 also specifies L_{Aeq} of 35 dB as the background sound level for classrooms, recognizing that children are less able to distinguish speech in noise than adults. NPS chairs a national working group (ASA in litt.) seeking to define standards of quality for acoustical environments and participates in an international working group with a similar charter (ISO in litt.).

With regard to appropriate metrics for evaluating noise impacts, following guidance represents an international perspective on the practices that have evolved in the context of community noise (WHO 1999):

> Where there are no clear reasons for using other measures, it is recommended that L_{Aeq},T be used to evaluate more-or-less continuous environmental noises. Where the noise is principally composed of a small number of discrete events, the additional use of LAmax or SEL is recommended. There are definite limitations to these simple measures, but there are also many practical advantages, including economy and the benefits of a standardized approach.

$L_{Aeq,T}$ extends the previous definition of L_{Aeq} by specifying the time interval of measurement. For Yellowstone, this will be $L_{Aeq,8h}$ referring to the 8 hours between 0800 and 1600. The same document discusses the use of order statistics to evaluate background sound levels. L_{90} or L_{95} can be used as a measure of the general background sound pressure level that excludes the potentially confounding influence of particular local noise events.

L_{90} and L_{95} represent the 90^{th} and 95^{th} order statistics for sound level measurements. In National Parks, these measurements are 1 second L_{eq} values. L_{90} means that 90% of the measurements are greater than this value. Miller (1999) recommended pairing percent time audible and L_{eq} for analyzing noise impacts in parks. This potential synergy between the audibility metrics used by NPS and the L_{eq} metrics underlying national and international standards merits brief discussion. FICON (1992) noted that criticism of L_{dn} (and other L_{eq} metrics) often stems from "lack of understanding of the basis for the measurement, calculation, and application of that metric." Many people have difficulty relating an aggregate of perceived noise events to an average noise level, especially when the time interval for averaging extends over long periods. Hourly, daily, and even annual L_{Aeq} metrics have been used by some U. S. Federal Agencies.

NPS collects data identifying when noise is present: percent time audible. This offers NPS the opportunity to calculate the average noise level when the noise is present. This "audible L_{Aeq}" would utilize the aggregate duration of noise for the denominator of the average level, instead of the entire period of interest (0800 – 1600). This average noise level may be more readily interpreted for nontechnical audiences. Audible L_{Aeq} would also be logically and statistically independent of percent time audible. One metric addresses noise intensity when present; the other addresses how often noise is present. NPS noise assessments may require additional metrics, but this pair provides a foundation that blends NPS and community noise management practices.

3.6 Acoustical Conditions in Yellowstone National Park

Acoustical monitoring has been conducted in Yellowstone every year since the winter of 2002-2003. The primary purpose of acoustical monitoring is to characterize the park's natural acoustical environment and to measure the effects of snowmobile and snowcoach noise. In the absence of wind, Yellowstone's winter environment is characterized by some of the lowest natural sound levels ever measured (Burson 2006). Data collected using a GRAS 40HH ½" low-noise microphone system (microphone, preamplifier, and separate power supply) revealed L_{A50} values of 16.6 dB and 9.9 dB. Measured sound levels were occasionally biased upwards by the intrinsic noise level of these low-noise microphones (L_{Aeq} of 6.5 dB). L_{A50} represents the median of L_{Aeq}, 1s measurements. This metric is less sensitive to the extreme values in the measurements and bias due to intrinsic sensor noise, and offers an interpretation more directly relevant to listener experience: the level exceeded half of the time.

NPS standard sound monitoring equipment (electronic noise floor (L_{Aeq}) of about 18 dB) has been used to collect data from 21 sites in the park (Burson 2010). Hourly L_{50} and L_{90} summaries from these sites show that the sound level measurements are often biased upwards by the noise floor of these instruments. Very low background sound levels are partly responsible for the percent of the day (0800-1600) that OSV noise is audible. Burson (2009) reported that OSV nose is audible an average of 60% of the day in developed areas (55-65%), 39% in travel corridors (24-55%), and 15% in backcountry areas (0-26%). These measurements were made in the context of an average of 252 snowmobiles and 28 snowcoaches touring the park each day.
The spatial extent of the park affected by OSV noise is affected by the source noise levels of individual vehicles and the degree to which they aggregate such that their noise energy is additive. The percent time audible is also affected by noise source levels. Louder sources are audible at longer distances, so each event will be audible for a longer period. Source noise levels are represented in the NPS monitoring data by peak measured sound levels, which have been measured along travel corridors since winter 2003. These data show that peak OSV noise L_{Aeq}, 1s values exceed 70 dB at a distance of 30 m (Burson 2004–2009).

In order to document loud events in travel corridors, acoustical monitoring at Yellowstone has incorporated the capacity to record audio data for loud events. “These event thresholds were generally set at 70 dBA and 1 second (fast) and 50 dBA and 10 seconds (slow), but were adjusted depending on location and wind exposure (Burson 2005).” Monitoring from 2004 to 2009 indicates that snowcoaches are responsible for 94% of loud noise events in YNP road corridors (Burson 2004-2010). BAT noise specifications have not been developed for snowcoaches. Speed of travel, track conditions, snow accumulation on the drive train, and presence of snow berms or obstructions also contribute to the varying sound levels produced by OSVs (Scarpone et al. 2009). Snow groomers may be the loudest OSV in the park, though they largely operate outside the snow touring period of 0800-1600. They are also the slowest OSV, so

the audible duration of their noise events will be longer than any other vehicle. Data from the North Twin Lake and Madison Junction monitoring locations (30 meters from snow roads) show that nocturnal noise events from groomers can be comparable to the loudest groups of OSV that occur during the day (Burson 2009).
All touring snowmobiles conform with BAT requirements. Concessioner and personal snowmobiles for staff residents are not all BAT (some remain two-stroke technology). These were responsible for some of the loud sound events in the park (Burson 2004-2009). The percentage of administrative snowmobiles using BAT has steadily increased, from an estimated 30% in 2004 to around 70% in 2009 (Sacklin pers. comm.).

Commercial guiding results in grouping of snowmobiles. Groups of snowmobiles have a higher effective noise level, because their noise energy adds together, but their spatial zones of audibility overlap substantially. The duration of audibility for the group will be much less than the aggregate duration of audibility had the snowmobiles traveled separately (NPS 2008). Average group size for snowmobile tours was 7.25 vehicles (Burson 2009), implying that the group noise source level was about 8.6 dB higher than the single snowmobile noise level. 8.6 dB assumes the vehicles are approximately equidistant from the measurement location. For seven snowmobiles extending along 200 m of road, the aggregate level at 100 m distance from the road will be 7.1 dB. At 1 km, the aggregate level will be 8.4 dB.
Hastings et al. (2008) showed that BAT snowmobiles were 3-4 dB quieter than snowcoaches when evaluated under similar test conditions. Thus, groups of snowmobiles may project higher noise levels than individual snowcoaches to sites far away from the road. Snowmobile groups tend to move faster than snowcoaches, so the durations of snowmobile audible events can be lower than snowcoaches. Burson (2009) documented aggregates of guided snowmobile groups that numbered up to 31 vehicles, and snowcoaches may also aggregate in small groups at times. The high effective source levels from these exceptional groups will be audible at greater distances than more typical groups.

In recent winters, the average number of visitor snowmobile groups has been similar to the average number of snowcoaches entering the park each day (31 and 29, respectively in 2008-2009: Burson 2009). Remote soundscape monitors collected audible noise data and combined these data with a separate observational study conducted at various locations along travel corridors and at developed sites; for a total of about 190 hours over the course of five winters from 2005-2009. Out of all motorized sounds observed where observers could differentiate the source of the sound, guided snowmobiles accounted for about 34% of overall audibility, while commercial snowcoaches accounted for approximately 23% overall audibility. Administrative snowmobiles accounted for 16.5% overall audibility and administrative snowcoaches for 2.7% of audibility. Aircraft, groomers, or unknown accounted for 28%. The same study found that administrative snowmobile groups accounted for 63% of the total number of audible groups traveling in developed areas, while administrative snowcoaches accounted for 18% of the total number of audible snowcoaches in developed areas (Burson 2009, Appendix E).

In general, monitoring data show that snowcoaches are audible for less time than snowmobiles during an average day, but are responsible for most of the loudest events in snow road corridors. At sites well outside the road corridors, the aggregate noise from groups of snowmobiles may match or exceed snowcoach noise levels. Requiring BAT for snowcoaches would substantially reduce the loud noise events in road corridors.

The relationship between OSV traffic levels and the audibility of noise is not as direct and simple as it might seem. In the 2008 Interim Winter Use Plan/EA (NPS 2008), figure 3-1 shows a general positive relationship between snowmobile traffic levels and the percent time audible for all OSVs. However, there is substantial scatter in the data. Less than 9% of the overall variation is explained by the fitted straight line. One date having approximately 260 snowmobiles had nearly 10% less audibility than another date having 140 snowmobiles. Many factors can affect audibility (Hendrych and Hynek 2008). Figure 3-2 illustrates that wind diminishes the audibility of OSV noise. Wind affects the propagation of sound, wind interacts with vegetation and terrain to elevate background natural sound levels, and wind flowing around the ears generates additional sound that makes it harder to hear OSV noise. In addition, wind may alter OSV use patterns.

Figure 3-1 from the 2008 EA (NPS 2008) also does not factor in snowcoach traffic or administrative OSV traffic, and cannot account for potential differences in routes taken by OSV. Total percent time audible can be diminished by clustering vehicles so that audible events overlap (NPS 2008). Commercial snowmobiles travel in groups, and several groups may overlap with each other (in audibility) during high traffic intervals and routes like morning travel to Old Faithful or afternoon travel back to the entrance gates. In contrast, administrative vehicles are often solitary and travel to and from destinations as needed throughout the day, greatly increasing the percent audibility of OSVs in the park.

Data from one monitoring site (Madison Junction; located 30 m from the West Entrance Road) illustrates the complexity of the relationship between OSV traffic levels and audibility. At high traffic levels over President's Day weekend in the 2002-2003 season (before BAT or commercial guiding were required) the percent time audible was 93% (NPS 2008). This was reduced to about 25% audibility over the same weekend winter 2003-2004. What changed? The average daily traffic level dropped from 1,679 snowmobiles to 589 snowmobiles and a substantial number of the snowmobiles were BAT. However, during the following season, percent time audible at the same site over President's Day weekend increased to 61%, despite a daily average of 506 snowmobiles per day. Despite an overall positive trend in the relationship between OSV traffic level and audibility, there is additional variation due to many factors. Peak traffic over President's Day weekend may not have varied in direct proportion to the daily average traffic levels for the season, snowcoach traffic increased, administrative OSV use may have varied, and weather could have affected visitor use patterns, sound transmission, and listening conditions. Percent audibility for this zone averaged 55% in 2006-2008 (Burson 2009) and L_{Amax} exceeded 70 dB in most hours of measurement between 0800 and 1600 (Burson 2009).
In 2004 at Mary Mountain Trail (in a transition zone located 305 m from the snow road), OSVs were audible an average of 32% of the time (Burson 2004). Other research (Hastings et al. 2006) and a published account (Yochim 2009) have shown mechanized noise may be audible to humans in some areas up to 16 km from travel corridors. All OSVs exhibit noise spectra with prominent tonal peaks due to engine rpm and drive train noise. When those tonal peaks occur at low frequency, they can be perceptible at very long distances. Low frequency sounds are weakly absorbed by the atmosphere and tonal sounds are readily perceived by visitors (Menge et al. 2002, Hastings et al. 2008).

3.7 The Merits of Alternative Metrics for Evaluating Acoustical Environments

All of the metrics discussed above are founded on human auditory perception. A-weighting discounts sound energy as a function of frequency to render an approximate measure of equivalent perceived loudness for humans. Humans are maximally sensitive to sound energy between 1 kHz and 6 kHz, with dramatic reductions in sensitivity near the frequency limits of human hearing (Crocker 1997). Percent time audible refers to the threshold of human detection for noise. This emphasis on noise impacts to humans is logical, given the origins of noise management, but it may not be appropriate to evaluate the effects of noise on the physical resource. The adequacy of metrics based on human auditory perception has been discussed within NPS for some time (Selleck 2010). However, the treatment of this issue in other scientific fora are not known.

Perceptual or psychoacoustic metrics are designed to provide quantitative measurements that correspond to objective perceptual attributes (Fastl and Zwicker 2007). These have been widely applied to product sound quality assessments, but they have not previously been utilized to evaluate acoustical environments in parks and protected natural areas. Spectral measures refer to sound level summaries that are applied to distinct frequency bands. All calculations of audibility or detectability depend upon this type of acoustical data. The other proposed metrics have not been widely used for acoustical evaluation in any setting.

3.8 Noise Modeling

Noise models are widely used to evaluate the spatial extend of impacts from many forms of transportation and industrial noise. They provide the most rigorous basis for evaluating alternatives and "what if" scenarios, and provide more extensive spatial coverage than can be achieved by monitoring efforts. Monitoring and modeling complement each other, as empirical data can be used to validate modeling results and identify potential corrections. Two models are presently available that can model the audibility of noise in park settings. The Integrated Noise Model (INM) was developed by the Volpe Transportation Center (Cambridge, MA) and is the FAA standard model for evaluating aircraft noise. The Noise Model Simulation (NMSim) was developed by Wyle Laboratories, Inc (Miller et al. 2003, Fleming et al. 2005). Both of these models were developed to model aircraft noise, but their sound propagation algorithms are applicable to noise from ground vehicles.

In 1998 an interagency, multidisciplinary noise model validation study was initiated to empirically test the ability of four noise models to predict the audibility of aircraft noise at Grand Canyon. Forty seven scientists and engineers from ten federal agencies and engineering companies participated in the study design, execution, and review of the results. The final report (Miller et al. 2003) concluded: "Overall, NMSim proved to be the best model for computing aircraft audibility, because it is shown to have the most consistent combination of low error, low bias, and low scatter for virtually all comparisons." A subsequent review by the Federal Interagency Committee on Aircraft Noise (Fleming et al. 2005) included the following statements comparing INM and NMSim:

- The components of both INM Version 6.2 and NMSim are based on well-established physics, and have been field validated.
- Substantial gains have been made with regard to understanding model-to-model differences; and many of those differences have been reduced or eliminated. However, when comparing INM Version 6.2 and NMSim, there still remain some differences, particularly with point-to-point comparisons.
- Both INM Version 6.2 and NMSim are performing equally well, on average, when compared with the "gold standard" audibility data measured in the GCNP MVS. GCNP MVS refers to Miller et al. 2003.

INM was used in the OSV noise study conducted by Volpe in support of the 2007 Yellowstone EIS (Hastings et al. 2006). This report found that the percent of the park area in which any OSV noise would be audible varied from 10-15% for the modeled alternatives. However, the 2007 EIS noted that INM underestimated the measured sound level of OSVs at eight of twelve monitoring sites in the park, and underestimated the percent time audible at seven of twelve sites (and overestimated audibility at one site).

INM integrates noise exposure from route segments for each vehicle; NMSim simulates the movement of each vehicle in greater detail. The simulation in NMSim provides the capability to generate animations, which can help nontechnical audiences visualize the dynamics of noise exposure in time and space. The NPS Natural Sounds and Night Skies Division has developed software frameworks to extend the utility of both INM and NMSim model output. This framework ingests noise model output data for each unique combination of vehicle type, route segment, and speed that could be an element of a management alternative. The output of these model runs, which can require hundreds of hours of compute time, is processed in relation to spreadsheets that specify how many vehicles are on each route for each alternative. The framework computes the composite noise exposures resulting from the combination of all OSV traffic in each alternative.

This framework has several benefits. New kinds of noise maps and tabular summaries are available, thanks to the flexible software structure of this iterative processing framework. More importantly, the consequences of revised alternatives can be evaluated in a few minutes, or about 1000 times quicker than would be possible if the revised alternative had to be modeled by running INM or NMSim again. The computations in this iterative framework utilize straightforward algebra to combine the noise model inputs, the exact same computations that the models would employ if they were used to process the composite alternatives.

INM and NMSim take slightly different approaches to noise modeling, but they should generate comparable results (Fleming et al. 2005). Continued use of INM offers the strongest basis of comparison between any forthcoming alternatives modeling and the previous results, because differences in model outputs will be entirely due to differences in model inputs (Hastings et al. 2006). Use of NMSim offers an opportunity to broadly cross-validate the results of the different noise models, and to identify specific modeling results that are contingent on the model used.

3.9 Conclusions

- Available community noise standards were not established to preserve the quality and character of acoustical environments, so the noise levels they specify will rarely be relevant to NPS resource management. However, the L_{Aeq} metric used in many of these standards may be useful, because it has been the subject of so much research and is used to characterize many noise sources. The audibility of noise has been central to all previous NPS assessments of noise impacts. Audibility data can be used modify L_{Aeq} to make these numbers easier to interpret, by averaging the noise level over the time when the noise is audible. Used in tandem, these two metrics can concisely represent the temporal extent of noise, as well average audible noise level.

- A measure of peak noise level was used in previous Yellowstone winter use environmental assessments; peak noise level metrics also appeared in the survey of acoustical experts. The significance of this kind of peak exposure will be easier to assess if the metric provides an indication of the duration of these levels of exposure. For example and L_1 metric indicates that noise exceeds this level 1% of the time.
- An L_{Aeq} of 35 dB appears in several standards addressing the quality of indoor spaces where good listening conditions are important. Application of ANSI S12.9-4 standards to OSV noise in Yellowstone suggests that 4% of park visitors would be highly annoyed by noise exposure at 35 dB. Given the community noise context for these standards, NPS may find choose to restrict these criteria to developed areas and travel corridors in the park.
- Two noise models are available that can evaluate the spatial extent of audible OSV noise in the park. They differ in some features, but are believed to yield similar results. Results from previous modeling efforts understated the spatial and temporal extent of audible OSV noise. Interpretation of future modeling results should be mindful of this discrepancy. Research aimed at understanding the causes of this discrepancy could help improve future models and enhance their interpretation.

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4. Wildlife

4.1 Background

4.1.1 Wildlife and Winter Use in Yellowstone National Park (YNP)

Winter in the higher elevations of the Yellowstone ecosystem is characterized by deep and prolonged snow conditions, extremely cold temperatures, and short daylight. Winter visitors to the park are able to access a unique ecosystem during a season when wildlife are coping with environmental extremes and may be conspicuous against a snowy background. However, these harsh environmental conditions heighten concerns about the additional stress placed on wildlife by the presence of visitors during the winter season.

OSV use in the park increased from the 1960s to the 1990s, peaking at over 140,000 vehicles days per approximately 80-day winter season, before subsiding to approximately 30,000 OSV vehicle-days during recent years. In addition to changing levels of winter OSV use, the past 30 years have also encompassed significant ecological changes such as post-1988 fire succession of forest cover (Schoennagel et al. 2008), elk population decline (Evans et al. 2006, Eberhardt et al.

2007), bison population increase (Fuller et al. 2007b), the reintroduction of wolves (Smith et al. 2003), and long-term drought (Vucetich et al. 2005). During the same period, the park implemented new long-term science and monitoring programs and sponsored studies of wildlife responses to winter use.

This section summarizes the state of knowledge of winter-use effects on wildlife in YNP drawing from research conducted in the park, as well as a larger body of pertinent research from other ecosystems. We identify key findings and deficiencies in current understanding of winter use effects on wildlife in YNP, and identify opportunities for monitoring and research to address questions than cannot be resolved presently.

4.1.2 Benchmarks and Desired Conditions

NPS management policies specify the Service's approach to biological resource management.

> *"The Service will successfully maintain native plants and animals by:*
>
> *• Preserving and restoring the natural abundances, diversities, dynamics, distributions, habitats, and behaviors of native plant and animal populations and the communities and ecosystems in which they occur*
>
> *• Restoring native plant and animal populations in parks when they have been extirpated by past human-caused actions*
>
> *• Minimizing human impacts on native plants, animals, populations, communities, and ecosystems, and the processes that sustain them."* (NPS 2006: 4.4.1)

This language clearly emphasizes maintaining populations through healthy biological systems and preserving natural processes, which is a central tenet of conservation biology. As indicated above, minimizing disturbance to individuals is an element of management in the park. However, NPS does allow removal of individuals from parks for approved research projects, to support restoration efforts elsewhere, or to meet specific park management objectives (NPS 2006: 4.4.2). The guiding criterion governing these decisions again refers to biological systems: “The Service may intervene to manage individuals or populations of native species only when such intervention will not cause unacceptable impacts to the populations of the species or to other components and processes of the ecosystems that support them" (NPS 2006: 4.4.2).

NPS explicitly recognizes this challenge of creating opportunities for visitor enjoyment while preserving resources and values unimpaired: "Virtually every form of human activity that takes place within a park has some degree of effect on park resources or values, but that does not mean the impact is unacceptable or that a particular use must be disallowed" (NPS 2006: 1.4.7.1). NPS management policies make it clear that determinations of impairment or unacceptable impacts are a matter of professional judgment by NPS staff, informed by science, consultation with other agencies, public stakeholder input, foundational management documents, and legislation (NPS 2006: 1.4.7).

4.2 Potential Responses of Individual Animals to Disturbance Associated with OSVs and Winter Use

OSVs and winter recreation in Yellowstone have the potential to influence wildlife at various levels of ecological organization (Figure 1). Motor vehicles, disturbances associated with motor vehicles, and other winter-use activities have been shown to affect individual animals in various ways. Examples include direct mortality or injuries from motorized vehicle strikes, noise interference that affects hearing and communication, and disturbance effects on physiology and behavior (Figure 1). Behavioral and physiological responses to disturbances may be reduced by animal experience through the process of habituation, which occurs when animals learn to minimize their response to a potential disturbance after repeated neutral or non-threatening exposures to the stimulus. If disturbances are sufficiently widespread, severe, or prolonged to affect vital rates of significant proportion of animals, then such individual-level affects may have measurable effects on wildlife populations (Figure 1).

4.2.1 General Evidence of Wildlife Responses to Motor Vehicles and Tourism

Collisions with Motor Vehicles

Motorized vehicles can affect animals directly through collisions. Impacts with wheeled vehicles can be an important source of mortality in some wildlife species (Dal Compare et al. 2007). Vehicle collisions were the greatest source of mortality for wood bison in the Nordquist herd of northern British Columbia, where 32 animals were killed by vehicle collisions in 2005 out of a conservatively estimated population of 67 (Rowe 2007). Other studies of demography and survival of ungulates in national parks and protected areas, however, have documented low rates of mortality resulting from vehicle collisions. For example, vehicle collisions were not identified as causes of bison mortality in Wood Buffalo National Park (Bradley and Wilmshurst 2005), Badlands National Park (Berger and Cunningham 1994), Wichita Mountains Wildlife Reserve (Shull and Tipton 1987), the Mackenzie Bison Sanctuary (Larter et al. 2000), or the Henry Mountains in Utah (Van Vuren and Bray 1986). In a study of cause-specific elk mortality in Theodore Roosevelt National Park, there were no vehicle strike mortalities; indeed, rates of non-hunting mortality were among the lowest reported for elk despite the presence of motor vehicles (Sargeant and Oehler 2007). Of 28 radio-collared elk that died during a study in Wind Cave National Park, only one death was due to collision with a motor vehicle (Sargeant et al. 2011). Ideally it would be helpful to know how the risk of wildlife mortality from motor vehicle collision is affected by traffic volume, but little published research has addressed this. In one study in the Netherlands, badger mortality was higher on smaller roads with lower traffic volume than on larger, busier roads (van Langevelde et al. 2009) , indicating that factors besides traffic volume may influence rates of wildlife-vehicle collisions.

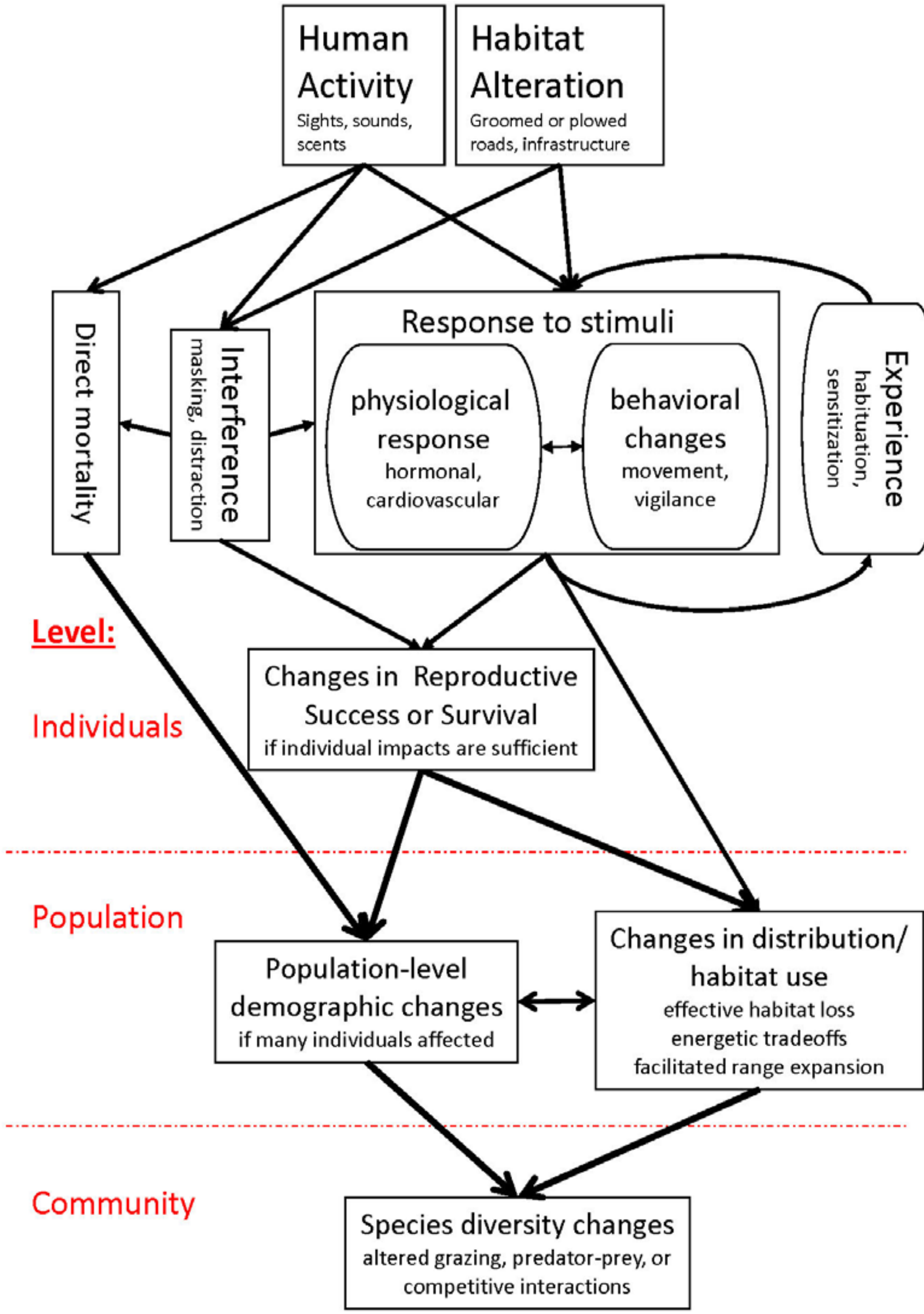

Figure 1 Wildlife Conceptual Model

Acoustic Interference and Masking

Motor vehicles may also interfere with auditory perceptions of individual animals (Figure 1). Noise may disrupt communications used to advertise reproductive and territorial status, choose mates, warn of potential dangers, or maintain group cohesion (Bowles 1995, Barber et al. 2010). For example, during breeding seasons, anthropogenic noise can interfere with bird songs (e.g., Mockford and Marshall 2009, Parris and Schneider 2009, Hu and Cardoso 2010, Verzijden et al. 2010). Noise also interferes with frog vocal communication (Lengagne 2008) and orientation towards calls of the opposite sex (Bee and Swanson 2007). Social animals such as elk and several bird species that winter in YNP could also be affected by masking if vehicle noise drowned out contact calls (cf. Marler 2004) or alarm calls (cf. Caro 2005, Sloan and Hare 2008).

Aside from intentional communication, motor vehicle noise may also interfere with natural sounds that animals use for foraging, habitat selection, or avoiding predation (Bowles 1995, Barber et al. 2010). For example, some birds (Knudsen and Konishi 1979, Rice 1982, Montgomerie and Weatherhead 1997) and bats (Hamr and Bailey 1985, Neuweiler 1989) rely on sound to locate prey. Indeed in a laboratory study, road noise from 3-8k Hertz was avoided by foraging insect-gleaning bats (Schaub et al. 2008). Some bat species have also been shown to be much less likely to cross roads with traffic (Kerth and Melber 2009). Several species have also been shown to respond to the sounds of their predators' footfalls or wingbeats (Bernal et al. 2007, Magrath et al. 2007) or even to the sound of fire (Grafe et al. 2002).

Wildlife Behavioral Responses

Wildlife may respond behaviorally to human disturbance by increasing their level of vigilance, which has been shown in bison to reduce forage intake during summer (Fortin et al. 2004). Many animals display increased levels of vigilance in areas that are more prone to disturbance (Manor and Saltz 2003, Quinn et al. 2006, Jayakody et al. 2008, Pangle and Holekamp 2010). Pronghorn spent 25% more time being vigilant when less than 300 meters from a road, and correspondingly spend less time foraging (Gavin and Komers 2006). Elk in Canada exhibited higher vigilance in the presence of roads with vehicular traffic as compared to closed roads (St. Clair and Forrest 2009). Lions in South Africa displayed more disturbance-related behaviors in the presence of tourists (Hayward and Hayward 2009). Wild reindeer in Norway were more vigilant to humans on foot during winter than at other times of year (Reimers et al. 2009).

Wildlife also may respond behaviorally to human disturbance by moving away from the disturbance. In Oregon, elk and deer movements were elevated by all-terrain vehicle (ATV) use, mountain biking, and horseback riding (Wisdom et al. 2004). In that same study, the probability of flight responses in elk declined with distance, with little effect for each activity beyond the following distances: ATV and mountain bike (1500 meters), horseback riding (750 meters), and hiking (500 meters). Disturbance by hikers and mountain bikes within 100m led to a 70% probability of fleeing for bison, pronghorn, and mule deer in Utah (Taylor and Knight 2003). Noise from aircraft has also been shown to disturb mountain goats (*Oreamnos americanus*) in Alaska (Goldstein et al. 2005) and harlequin ducks (*Histrionicus histrionicus*) in Labrador (Goudie 2006). Reindeer on Svalbard Island reacted to snowmobiles as far as 640 meters away (Tyler 1991). For other species, disturbance distances were much lower; responses of white-tailed deer in Wisconsin to snowmobiles were greatest when the animals were less than 61 meters from the trail (Eckstein et al. 1979). High snowmobile traffic elicited greater flight responses from wild reindeer on Svalbard Island than did lower traffic (Tyler 1991), and high human traffic in general has led to increased behavioral responses in a variety of ungulate species (Denniston 1956, Walther 1969, Rowe-Rowe 1974, Cassirer et al. 1992, Recarte et al. 1998, Colman et al. 2001). However, desert bighorn sheep (King and Workman 1986) and muskoxen (Hone 1934) responded more strongly to low-volume human traffic than to high-volume traffic. Other ungulate species show no effect of human traffic level on flight responses (Alados and Escos 1988, Cassirer et al. 1992). Displacement behavior of moose and elk in Alberta was likewise not related to ski-trail use intensity (Ferguson and Keith 1982). For other species, the volume and characteristics of human traffic may be irrelevant; for example, movements of the white-footed mouse and eastern chipmunk were thought to be constrained by the physical characteristics of the roadbeds themselves, not traffic per se (McGregor et al. 2008).

Displacement by OSV-induced disturbance may be related to disturbance intensity. At a site in Minnesota with limited snowmobile activity, snowmobiles elicited changes in white-tailed deer home-range size, movement, and mean distance from snowmobile trails. But at another site subject to an average of 10 snowmobiles per day on weekdays and 195 per day on weekends, no effects of snowmobiles on deer behavior were observed (Dorrance et al. 1975). At the second site, deer moved from snowmobile trails upon initial disturbance by light snowmobile traffic, but after the snowmobiling ceased the deer returned to areas near the trails within hours (Dorrance et al. 1975).

Wildlife Physiological Responses

Human disturbance may induce physiological stress responses in some species. Effects of stress may be reflected by increased production of glucocorticoid hormones or by other physiological measures, including increased heart and respiration rates (Gabrielsen and Smith 1995). Glucocorticoid hormones facilitate rapid physiological and behavioral responses of animals to changing environments and perceived threats, and provide a direct measure of the endocrine response to stress. Consequently, concentrations of glucocorticoid hormones in blood or feces may be useful indicators of physiological stress, potentially revealing effects of human disturbance before demographic consequences are evident (Walker et al. 2008). On the other hand, relations between environmental stresses, glucocorticoid levels, and vital rates (i.e., mortality and natality) are not predictable or well-understood (Millspaugh and Washburn 2004). Although numerous examples document elevated glucocorticoid levels in animals exposed to stress, interpretations and consequences of elevated glucocorticoid levels may be unclear.

Examples of elevated glucocorticoid levels associated with human disturbance include increased corticosterone metabolites in capercaillie (*Tetrao urogallus*) feces near ski areas in Germany (Thiel et al. 2008). Roads significantly increased stress responses in elk in the Black Hills, South Dakota (Millspaugh et al. 2001). Lions in South Africa had elevated breathing rates—a potential metric of stress—in response to the presence of tourists (Hayward and Hayward 2009). In some cases, physiological responses occur even without apparent behavioral responses (MacArthur et al. 1982, Wilson et al. 1991). On the other hand, white-eyed vireos (*Vireo griseus*) showed no heart-rate responses to human disturbances despite behavioral responses (Bisson et al. 2009).

Fewer studies have clearly linked glucocorticoid responses to changes in reproduction, survival or fitness traits of individual animals. However, weights of fledgling yellow-eyed penguins in New Zealand were correlated with corticosterone levels in their parents (Ellenberg et al. 2007). Further, experimental dosing with corticosterone has been shown to affect territorial behavior in adult pied flycatchers as well as parental feeding of nestlings and fledgling rates (Silverin 1986).

Wildlife Energy Budgets

Energy is a useful currency for studying the effects of disturbances on individual animals. The individual animal's nutritional well-being, related to its chances for survival and reproduction, reflects the net budget of calories assimilated through foods and expended for physiological maintenance, growth, reproduction, thermoregulation, and all required activities, including responding to disturbance (Moen 1973). The average energetic cost of standing is 25% greater than that of lying in ungulates (Parker et al. 1984), suggesting that disruption of resting may elevate energy costs. Bald eagle feeding was reduced by 35% in Washington due to disturbance by recreational visitors (Stalmaster and Kaiser 1998). Following disturbance by off-trail skiing in Sweden, moose increased their movement speeds 33 times during the first hour, and movement rates remained elevated for 3 hours following disturbance (Neumann et al. 2010). These responses led to a doubling of energetic expenditure during the first hour after disturbance, and often to the animals leaving the area (Neumann et al. 2010). Grizzly bears disturbed by mountain climbers in Montana spent 53% less time foraging which led to a reduced energy intake of 12kilocalories per minute (White et al. 1999). Bradshaw et al. (1998) estimated that exposure to a single disturbance event from petroleum exploration cost an individual woodland caribou 3.5-5.8 megajoule of energy, and that caribou would have to be exposed to 27 to 89 such events to lose 15% or 20%, respectively, of their body mass over winter. Mule deer increased their daily metabolizable energy expenditures 2 to 4% through fleeing from people on foot, and 0.4 to 0.8% through fleeing from snowmobiles (Freddy et al. 1986). Disturbance by hunting reduced energy gain by snow geese (*Anser caerulescens*) (Bechet et al. 2004). Brent geese (*Branta bernicla*) in a national park in Germany had 8.7 to 27.5% lower hourly net energy intake on days with high disturbance frequency as opposed to days with lower disturbance frequency (Stock and Hofeditz 1997). In a different study, brent geese in Norfolk had 10.8% increased hourly energy expenditure on days with high versus low disturbance intensity (Riddington et al. 1996). Conversely, not all wildlife behavioral responses to human disturbance translate into impacts on energy budgets. For example, although human disturbances induced some behavioral responses in white-eyed vireos, increases in energetic expenditure from disturbances lasting 1 to 4 hours were undetectable (Bisson et al. 2009).

Variability in Wildlife Responses

Wildlife behavioral responses to human disturbance are highly variable. A recent analysis of ungulate behavioral responses to human disturbances indicated that ungulates in hunted populations are more likely to flee from disturbance than those in unhunted populations, although the effects of hunting may be ameliorated by habituation to non-threatening activities outside the hunting season (Stankowich 2008). In general, larger groups show a greater tendency to flee from approaching disturbances than smaller groups in both ungulates (Stankowich 2008) and birds (Frid and Dill 2002). Ungulates may also be more prone to flee from human disturbances when in open habitat than forest (Stankowich 2008). Wildlife behavioral responses to human disturbance can also vary with season, though the effects are not consistent in direction across studies or species. Ungulate movement responses to approaching vehicles were stronger in winter and the calving season than in other seasons for barren-ground caribou (Calef et al. 1976), wild reindeer (Thomson 1972), and blesbok (Rowe-Rowe 1974). However, movement responses were weaker in winter than in other seasons for European chamois (Hamr 1988). There was no effect of season on flight response for reindeer on Svalbard Island (McCourt et al. 1974). Across ungulate species, females and groups with offspring respond most strongly to approach by humans (Stankowich 2008), though this effect was not observed in elk in Rocky Mountain National Park (Schultz and Bailey 1978) or caribou in the Yukon Territory (Horejsi 1981). In carnivores, differential responses to disturbance based on sex are more difficult to predict. Adult female grizzlies in Banff showed the strongest avoidance of roads and vehicle traffic (Gibeau et al. 2002). Likewise, polar bear responses to approaching snowmobiles on Svalbard Island were strongest in females with cubs (Andersen and Aars 2008).However, male polar bears had greater vigilance responses to tundra vehicles than females in another study (Dyck and Baydack 2004).

Many wildlife species react more strongly to humans on foot or on skis than to motor vehicles. Waterbird (Klein 1993) and bald eagle (Stalmaster and Kaiser 1998) reactions were generally stronger to humans on foot than to vehicles. Mule deer reactions were more intense following pedestrian disturbance than disturbance by snowmobiles (Freddy et al. 1986). In general, ungulates also respond more strongly to humans on foot than to motor vehicles or anthropogenic noise, both behaviorally (Stankowich 2008) and physiologically (e.g., MacArthur et al. 1982).

However, wild reindeer in Norway responded similarly to skiers and snowmobiles (Reimers et al. 2003) and bison in Saskatchewan were as likely to flee from people on foot as from snowmobiles (Fortin and Andruskiw 2003). Responses of elk in Oregon to ATVs were stronger than the responses to hikers (Naylor et al. 2009).

Finally, wildlife responses to tourism-induced disturbance are generally much lower when the disturbances are at least somewhat predictable in time and space (Stemp 1983, Knight and Cole 1995, Canfield et al. 1999). For example, off-trail skiing and hiking (spatially unpredictable) induced stronger reactions than trail-based recreation in golden plovers (*Pluvialis apricaria*) (Finney et al. 2005), American robins (*Turdus migratorius*) (Miller et al. 2001), marmots (*Marmota marmota*) (Mainini et al. 1993), mule deer (Miller et al. 2001, Taylor and Knight 2003), meadowlarks (*Surnella neglecta*) (Miller et al. 2001), and vesper sparrows (*Pooecetes gramineus*) (Miller et al. 2001). Further, mule deer in Alberta that were accustomed to ATVs changed feeding schedules, increased use of cover, and altered home ranges when they were experimentally harassed by following them using ATVs for nine minutes daily over a 2-week period (Yarmoloy et al. 1988). Mule deer in Utah had a 70% probability of fleeing from trail-based recreationists within 100 meters, but a 96% probability of fleeing from off-trail recreationists at the same distance (Taylor and Knight 2003). Off-track boats also generated more intense responses in common terns (*Sterna hirundo*) than boats using established channels (Burger 1998).

Wildlife Habituation and Tolerance

Habituation is the process by which animals learn to minimize their response to a potential disturbance through repeated neutral or non-threatening exposures to the stimulus. Habituation may result in energetic savings to animals not inclined to flee from neutral stimuli, but may also increase vulnerability to disease, natural predators, or increased mortality risks from vehicle collisions (Boyle and Samson 1985, Bejder et al. 2009). Habituation should not be confused with tolerance, which is defined as the acceptance of disturbance. An animal may tolerate disturbance stimuli for a variety of ecological reasons separate from the behavioral process of habituation. For example, individuals may tolerate disturbance if they cannot afford energetically to respond, need to remain in an area to avoid predation risks or competition, or if there are no suitable habitats nearby in which to move (Gill et al. 2001, Frid and Dill 2002, Bejder et al. 2009).

The process of habituation has been demonstrated in many free-ranging populations exposed to disturbances. For example, Magellanic penguins in Argentina habituated to ecotourism disturbance within five days—reducing both their vigilance to approaching humans and their corticosterone response to capture and handling (Walker et al. 2006). In general, ungulates show reduced behavioral responses to human disturbance in areas with higher exposure to disturbance, though this effect is highly variable (Stankowich 2008). For example, caribou (Thomson 1972, Duchesne et al. 2000) and moose (McMillan 1954) showed decreased flight response over time, while responses of chamois (*Rupicapra rupicapra*) to disturbance by hikers reached an asymptote (i.e., leveled off) over time (Enggist-Dublin and Ingold 2003). Mule deer and bighorn sheep had increased heart rates in response to simulated jet over-flights in Arizona, but heart rates returned to normal after 60 to180 seconds (Weisenberger et al. 1996). Moreover, heart rates and behavioral responses decreased with increasing exposure to over-flights (Weisenberger et al. 1996). However, elk in Banff National Park showed an increase in response intensity after experimental harassment treatments (Kloppers et al. 2005). Dall sheep (*Ovis dalli*) did not habituate to lower frequency helicopter disturbance, and showed increasing intensity of flight responses over time to high frequency helicopter disturbance (Frid 2003). Moose in Sweden did not appear to habituate to disturbance by cross-country skiers (Neumann et al. 2010). Habitation can also vary depending on the time scale used. For example, the flight-initiating distance between wild reindeer in Norway and the approach of humans on foot decreased with repeated exposures within a single day, but increased over years between 1992-2002 (Reimers et al. 2009). Habituation to stimuli may be highly variable among individuals within a population (Runyan and Blumstein 2004, Ellenberg et al. 2009), which may lead to the uneven distribution of habituated animals near disturbances and less habituated animals further from the source of disturbance (Carrete and Tella 2010). The propensity of animals to habituate to disturbance may also increase with age and experience (Bellefleur et al. 2009). Habituation also occurs in areas subject to predictable noise and disturbance patterns. For example, lackbirds born in cities had reduced stress responses to urban disturbance than individuals born in the forest (Partecke et al.

2006). Marmots in the Alps habituated to hikers that stayed on designated paths (Mainini et al. 1993).

It is hard to generalize about patterns of wildlife habituation to human disturbance because, in many cases, responses are specific to certain species (Belanger and Bedard 1990) and individualistic (Runyan and Blumstein 2004, Ellenberg et al. 2009). Further, many factors condition an animal's responses to disturbance, often obscuring the distinction between habituation and tolerance. The decision of an animal to move from a disturbed area is based on a number of factors including the quality of the site occupied, distance to and quality of other sites, relative risk of predation or competition, dominance rank, and investment a given individual has made in its current site (Gill et al. 2001). Animals with no suitable habitat nearby or within traveling distance may be constrained from movement despite the disturbance (Frid and Dill 2002). Beale and Monaghan (2004a) used experimental techniques to show that turnstones (*Arenaria interpres*) that experienced higher feeding rates were more likely to move away from disturbance than were animals with fewer feeding opportunities, supporting the concept that seemingly indifferent animals may actually be enduring the effects of the disturbance because their options for response are limited or unfavorable.

4.2.2 Evidence of Wildlife Responses to Motor Vehicles and Winter Use in Yellowstone

Collisions with Motor Vehicles

Twenty-four individuals of six mammal species are recorded as having been killed by OSVs in YNP from 1989-2010. These documented cases of vehicle-caused mortality all occurred before the 2003-04 winter season when it was first required that all recreational snowmobile users travel with a commercial guide in the park (see Appendix 1). Only three elk were killed during this time interval, out of an estimated population size (1989-2004 average) of approximately19,000 (Eberhardt et al. 2007). For bison, 13 individuals were killed by OSVs from 1989-2010. This is compared to an estimated population size (1989-2005 average) of approximately 3,340 (Treanor et al. 2007) and also approximately 255 bison (1989-2005 average) culled from the population per year (Treanor et al. 2007).

Wildlife Behavioral Responses

Several studies have assessed the effects of OSVs and winter recreation on wildlife in Yellowstone. Aune (1981) found that the largest impacts of snowmobiles on wildlife distribution occurred within 60 meters of groomed trails, and that elk disturbed by snowmobiles fled an average of 34 meters. Borkowski et al. (2006) observed a total of 6,508 encounters between park wildlife and OSVs (or humans dismounting or exiting) between 1999 to 2004, while White et al. (2009) observed 5,688 such encounters between 2002 and 2006. Collectively, all species exhibited non-travel responses (no response, look/resume, alert response) to human activities at least 90% of the time (Table 1). All species fled or took flight less than 6% of the time. Defensive reactions of wildlife to human activities were rare.

Table 1. Observed responses of bison and elk to OSV and human disturbance in Yellowstone National Park.

Observed Response	**Bison**		**Elk**		**Trumpeter Swans**	**Bald Eagles**
	Borkowski et al. 2006	**White et al. 2009**	**Borkowski et al. 2006**	**White et al. 2009**	**White et al. 2009**	**White et al. 2009**
No Apparent Response	81%	80%	48%	48%	57%	17%
Look-Resume	8%	9%	32%	27%	21%	64%
Alert	2%	3%	12%	17%	12%	9%
Travel	7%	5%	6%	5%	9%	4%
Flight	1%	2%	2%	2%	1%	6%
Defensive	<1%	<1%	<1%	<1%	0%	0%

White et al. (2009) examined relations between movement responses of wildlife and factors describing the context, qualitative nature, and intensity of human disturbances. For bison, elk, trumpeter swans, and bald eagles, the odds of a movement response diminished with increasing distance from the road. Probabilities of displacement decreased with increasing group sizes for bison, swans, and elk in thermal habitat, but elk in aquatic or unburned forest habitat were more likely to move when in larger groups. Factors that increased the odds of movement included larger numbers of snowmobiles, larger numbers of snow coaches, increased interaction times, and some species-specific habitat effects. Further, probabilities of movement increased when humans stopped, dismounted, and approached wildlife or when animals were moved off the road by passing OSV's. Probabilities of movement were greater for animals exposed to snow coaches than for those exposed to snowmobiles. The maximum probability of movement was reached at a threshold of 1to 3 coaches depending upon the wildlife species under consideration. There was no threshold in the numbers of snowmobiles eliciting a movement by elk or swans, but the probability of movement response reached an asymptote at 7 snowmobiles for bison and 18 snowmobiles for bald eagles.

Certain wildlife species in Yellowstone may also respond behaviorally to skiers and other backcountry recreationists. The distance at which elk in Yellowstone started to move in response to disturbance by skiers ranged from 15 meters in Mammoth to 400 meters in the Lamar Valley and Stephen's Creek (Cassirer et al. 1992). Once disturbed, elk in the two areas moved a median of 40 and 1,675 meters, respectively(Cassirer et al. 1992). Aune (1981) estimated average flight distances of elk disturbed by skiers in Yellowstone at 54 meters, and noted that elk responses were stronger when skiers were off-trail rather than on established trails. Finally, there is some concern that increased backcountry recreation in steep, high elevation terrain could disturb denning grizzlies in Yellowstone (Podruzny et al. 2002).

Wildlife Physiological Responses

There is equivocal evidence as to whether winter use affects physiological stress responses in Yellowstone wildlife. Based on preliminary analyses, Creel et al. (2002) reported that glucocorticoid levels increased as a function of daily snowmobile use in YNP, and that snowmobiles elicited greater stress responses than wheeled vehicles. However, subsequent analyses of a larger data set did not substantiate preliminary conclusions (Hardy 2001). Fecal glucocorticoid levels in bison were not significantly influenced by OSV recreation (Hardy 2001).

Wildlife Habituation and Tolerance

Some evidence suggests that certain wildlife species in YNP were habituated to OSVs and other human disturbances during winter. Bison were less likely to demonstrate vigilance behavior as cumulative visitation increased during winter, and were less likely to move from OSV-induced disturbances during winters with greatest visitation (White et al. 2009). Similarly, the probabilities of swans responding to OSV use decreased as cumulative visitation increased over winters (White et al. 2009). In contrast, the probabilities of elk responses to OSV's did not change as cumulative visitation increased (White et al. 2009), and elk did not appear to habituate to repeated disturbance by skiers in Mammoth, Lamar, and Stephen's Creek areas (Cassirer et al. 1992).

4.3 Potential Responses of Wildlife Populations to Disturbance Associated with OSVs and Winter Use

If a sufficient proportion of individuals experience changes in survival or reproduction due to human disturbance, there can be changes in overall population demography (age and sex class structure) and abundance (Figure 1). Moreover, to avoid negative physiological and demographic impacts, wildlife could potentially alter their distribution in response to roads and traffic noise.

4.3.1 General Evidence of Wildlife Population Responses to Motor Vehicles and Tourism

Wildlife Demography

Motor vehicles, and associated disturbances such as noise, can influence wildlife survival and reproduction, though the effects are inconsistent in magnitude and direction across species and localities. Many birds show reduced breeding success when exposed to disturbance by humans (Giese 1996, Verhulst et al. 2001, Beale and Monaghan 2004b, Ellenberg et al. 2006, Ellenberg et al. 2007). Human-induced disturbance had strong effects on population viability of endangered chough (*Pyrrhocorax pyrrhocorax*) in a protected area in Ouessant Island through reducing juvenile survival rates (Kerbiriou et al. 2009). Male boreal songbirds avoided territories near natural gas compressor stations, and those with noisy territories had less success in attracting females (Habib et al. 2007). These behavioral responses (which were closely related to reproductive success) were accompanied by a decrease in songbird density at compressor sites

(Bayne et al. 2008). Reduced pairing behavior in birds exposed to loud noise has also been demonstrated in lab studies (Swaddle and Page 2007). Birds within 100 meters of off-road vehicle trails in California had increased levels of nest desertion but reduced rates of nest predation (Barton and Holmes 2007). Olympic marmots , though more vigilant at sites heavily used by recreational tourists than at low-use sites, had comparable body condition, survival, and reproduction (Griffin et al. 2007). Likewise, disturbance by people on foot and snowmobiles that led to behavioral and energetic responses in mule deer did not lead to detectable effects on mortality or reproduction (Freddy et al. 1986).

Wildlife Distribution

Transportation corridors and associated noise can displace wildlife and influence species distributions (e.g., Reijnen et al. 1995, Reijnen and Foppen 2006, Benitez-Lopez et al. 2010). For small mammals the effects of roads are generally neutral or positive while for mid-sized or large mammals, the effects are neutral or negative (Fahrig and Rytwinski 2009). Moose in Quebec avoided highways and forest roads up to 500 meters away (Laurian et al. 2008), while elk responded to ATV disturbance up to 1 kilometer away or more (Preisler et al. 2006). Cole et al. (1997) documented a decrease in elk movement rates and home-range size following closure of roads. Noisy infrastructure reduced habitat usage by mule deer (Sawyer et al. 2006) and greater sage grouse (*Centrocercus urophasianus*) (Doherty et al. 2008). In contrast, elk in Waterton Lakes National Park, Canada, showed no change in distribution in relation to roads with vehicular traffic (St. Clair and Forrest 2009). Likewise, off-road vehicles did not alter American marten (*Martes americana*) habitat occupancy or daily activity patterns (Zielinski et al. 2008).

Impacts of motor vehicles and associated disturbance on wildlife distribution may be related to traffic intensity. Elk in Arizona occurred near a highway mainly during low traffic volume less than100 vehicles per hour). Habitat usage near the road decreased with increasing traffic volume (Gagnon et al. 2007). Mountain caribou in British Columbia strongly avoided areas with intense snowmobile activity (though the quantification of "intense" was not specified), suggesting that snowmobiles displaced the animals from high-quality habitat (Seip et al. 2007). Gazelles in China also avoided roads during high traffic-volume times of day (Li et al. 2009). In contrast, Benetiz-Lopez et al. (2010) found no significant effects of traffic intensity on bird displacement.

Moreover, bison winter use of meadows in Saskatchewan was not related to the number of human disturbances (Fortin and Andruskiw 2003).

Non-motorized winter use can also affect wildlife distribution. Caribou in Norway used areas within 15 kilometers of recreational cabins significantly less than expected due to disturbance by cross-country skiers (Nellemann et al. 2010). The location of capercaillie home-ranges in Germany was not affected by ski tourism, but the animals strongly preferred portions of their home-range away from heavily used areas (Thiel et al. 2008).

4.3.2 Evidence of Wildlife Population Responses to Motor Vehicles and Winter Use in Yellowstone

Wildlife Abundance and Population Dynamics

Road grooming to support OSV use in YNP has been thought to have facilitated an increase in bison abundance, but the balance of evidence seems to weigh against this hypothesis. Coughenour (2005) asserted an increased proportion of travel on packed snow could provide minor energetic savings which, without brucellosis risk management removals of bison, could compound over the course of many winters to affect population growth. However, estimated bison abundance increased exponentially from 1965-1994 despite a 20-fold increase in cumulative OSV use during the same period. Bison population growth was not related to cumulative visitation from 1965-2006 after removing the effect of management culls (White et al. 2009). Bison calf ratios were not significantly correlated with cumulative visitation. Survival rates of adult female bison were generally high (mean = 96%) from 1995-2001. Multiple studies have concluded that road grooming has not been an important factor in the increase in bison abundance in YNP (Wagner 2006, Bruggeman et al. 2007, 2009, Fuller et al. 2007a, White et al. 2009).

Likewise, there is little evidence that OSVs and winter use have affected elk populations in YNP. Calf ratios in the Madison headwaters population were not correlated with cumulative OSV use in the period 1991-2006 after the effects of snow water equivalent on calf recruitment were removed (White et al. 2009). Annual survival rates of adult female elk were higher than 90% and the population fluctuated around a dynamic equilibrium of about 550 elk during the period 1968-2004, despite increasing OSV use over that time period (White et al. 2009).

There is no evidence that OSV use has negatively affected bald eagle populations in Yellowstone. The numbers of nesting and fledgling bald eagles in YNP increased incrementally during 1987-2005 and were not correlated with cumulative winter visitation (White et al. 2009).

There is equivocal evidence that OSVs have had effects on trumpeter swan populations in Yellowstone. The number of residents adult and sub adult and cygnet trumpeter swans decreased during 1966-2005 and was negatively correlated with cumulative visitation. However, the decline was associated with a concurrent regional decline in swan numbers and was not considered to be a result of OSV use (Proffitt et al. 2009, White et al. 2009).

Annual population estimates for the reintroduced population of wolves in YNP indicates that the founding population of 31 wolves released during winters 1995 and 1996 increased to more than 160 individuals by 2003 (Smith et al. 2007), a period of high winter use by humans.

Wildlife Distribution

Although distributions of elk and wolves have been studied extensively in YNP (e.g. Smith et al. 2007, Messer et al. 2009), few studies have focused on effects of winter use on distribution patterns. Aune (1981) and Hardy (2001) stated that elk were temporarily displaced about 60 meters from busy road segments (e.g. Madison to Old Faithful) as cumulative OSV traffic increased. White et al. (2009) reported that human disturbance did not appear to be a primary factor influencing the distribution or movement of wildlife species they studied (bison, elk, trumpeter swans, and bald eagles) and concluded that individual responses that resulted in flight or other active behavior were apparently short-term behavioral responses without lasting influence on species distribution patterns. Moreover, White et al. (2009) concluded that bison, elk, and swans in YNP used the same core wintering areas in YNP during the last three decades despite considerable variation in the numbers and management of winter visitation to the park. The prevailing evidence suggests that winter snow pack conditions and heterogeneity is the primary factor influencing winter distribution of elk in central YNP (Messer et al. 2009).

Meagher (1993) suggested that road grooming or mechanical snow packing used for OSVs increased survival rates and facilitated movements of bison to areas near and beyond park boundaries. Several subsequent studies, however, did not support Meagher's hypotheses. Gates et al. (2005), Wagner (2006), Bruggeman et al. (2007), and Fuller et al. (2007a) found no evidence for an effect of road grooming on bison population growth and changes in winter range use were attributed to increasing bison abundance (Bjornlie and Garrott 2001, Gates et al. 2005, Bruggeman et al. 2009a, b). Winter travel by bison was negatively associated with road grooming and there was no evidence that bison preferentially used groomed roads in central YNP during winter (Bjornlie and Garrott 2001, Bruggeman et al. 2006, Bruggeman et al. 2009a) According to Bruggeman et al. (2007: 1411):

> "*Pronounced travel corridors existed both in close association with roads and distant from any roads, and results indicate that roads may facilitate bison travel in certain areas. However, our findings suggest that many road segments used as travel corridors are overlaid upon natural travel pathways because road segments receiving high amounts of bison travel had similar landscape features as natural travel corridors. We suggest that most spatial patterns in bison road travel are a manifestation of general spatial travel trends*."

Simulation models suggest snowfall typically would not constrain bison movements if roads were not groomed. However, Gibbon Canyon, where topography and deep snow may impede bison movements, may be an important exception. According to Gates et al. (2005):

> *"The Gibbon Canyon could serve as a topographic gate preventing Central Range bison from migrating to the Northern Range once snow accumulates. Given the large number of Central Range bison moving in some years to the north boundary and the potential consequence for inequitable culling of the Northern population, the role of the Gibbon Canyon as a potential barrier to movement is an important research question."* (Gates et al. 2005: 126)

Gates et al. (2005) concluded that although inter-range movements of bison in the park interior were not generally constrained by winter snow pack during most winters, it is not possible to rule out the possibility that road grooming through the Gibbon Canyon may have facilitated the development of a movement pattern from the interior of the park to the northern range historically.

4.4 Potential Responses of Wildlife Communities and Ecosystems to Disturbance Associated with OSVs and Winter Use

Changes in the abundance or spatial distribution of one species can potentially affect other species (Figure 1). For example, reduction in the numbers or spatial distributions of one species could open up habitat for other species that are either more tolerant of anthropogenic disturbance or that have no other habitat choices available (Boyle and Samson 1985, Gutzwiller 1995). Ultimately, community level changes and indirect ecosystem effects should be expected only if human impacts to individuals are sufficient to importantly alter species distributions and interactions. Otherwise, responses to OSVs at the individual and population level will be a negligible part of the complex ecological processes that structure ecological communities. Although there is some evidence of road- and noise-induced alteration of species interactions in other systems (discussed below), there is no such information specific to YNP.

General Evidence of Wildlife Community Responses to Motor Vehicles and Tourism

Roads and human-generated noise can alter species interactions if some species respond more strongly to disturbance than others (Slabbekoorn and Halfwerk 2009). For example, avoidance of roads by nest predators or competitors can increase reproductive success in birds (Francis et al. 2009, Leighton et al. 2010). Similarly, the recolonization of Grand Teton National Park by grizzly bears that avoid areas near paved roads has been associated with a change in the distribution of moose towards roads during the calving season (Berger 2007). Wild reindeer avoidance of a road in Norway led to reduced browsing on lichen up to 8 kilometers from the highway (Dahle et al. 2008).

It has been postulated that OSV use may increase competition between coyote and lynx in the Rocky Mountains by providing coyote access to deep snow environments, where they could prey upon snowshoe hare (Buskirk et al. 2000). Lynx have relatively large paws that enable them to more effectively utilize soft snow environments than coyotes. OSV trail networks create compacted snow conditions that may enable coyotes to extend their range. Bunnell et al. (2006) inferred a strong association between coyote movements and OSV trails in deep snow areas. In contrast, Kolbe et al. (2007) found that coyote trails were generally associated with firmer snow conditions, but were not especially associated with compacted OSV trails. Both Bunnell et al. (2006) and Kolbe et al. (2007) found that lynx preferred higher elevations than coyotes. Evidence that OSVs potentially increase competition between these two carnivore species is therefore equivocal.

4.5 Conclusions

The preceding review of literature highlights the potential for diverse effects of human disturbance on wildlife. However, the occurrence, nature, and magnitude of responses to disturbance clearly depend on complex, interacting factors that preclude broad generalizations. Such variability should temper inferences drawn about OSV use at YNP from observations of different species, environments, seasons, or types of disturbances. Similarly, generalizations drawn from studies conducted of wildlife in YNP may not apply equally to all species. Existing information nevertheless justifies the following conclusions:

- Available evidence, including accident records from Yellowstone and studies of cause-specific mortality in other parks, suggests collisions with OSVs are not a significant source of mortality for wildlife of Yellowstone National Park.

- For species that have been studied extensively, ecological processes, and not OSV use, are dominant influences on wildlife vital rates and rates of increase. Recreational use of OSVs in Yellowstone increased from <5000 vehicle-use days per annum during the mid-1960s to >140,000 during the late 1990s, then declined to ~30,000 vehicles per annum during recent years. Visitors are now required to travel in groups, with commercial guides, and the resultant increase in group sizes has further reduced frequencies of disturbance. Two-cycle snowmobile engines have been replaced by quieter 4-stroke engines, and travel speeds have been reduced, reducing the intensity of disturbances that occur. Notwithstanding the magnitude of these changes, existing evidence does not suggest associated changes in vital rates or abundances of key wildlife species. Such factors as weather, predators, and plant succession, and not winter recreation, are clearly responsible for most variation in vital rates and abundance of elk and bison. Wolf numbers increased rapidly following reintroduction of the species in 1996, and trends in trumpeter swan numbers parallel broader regional trends.

- Collectively, studies conducted to date suggest effects of OSV on individual animals have not had measurable detrimental effects. Any behavioral or physiological reaction to disturbance associated with OSV use qualifies as an effect on an individual animal. However, studies of ungulate physiology suggest habituation to predictable disturbances like those associated with OSV use in Yellowstone. Observations of bison, elk, trumpeter swans, and bald eagles, which evince awareness of passing OSVs but typically are not displaced, do not suggest substantial energetic costs. Elk and bison near roadways do not appear to exhibit elevated levels of stress hormones attributable to OSV traffic. Effects of OSV use on the dynamics of intensively studied species clearly are subsidiary to effects of ecological processes, hence effects on individuals are either very slight or affect small proportions of populations.

- Current evidence does not support the notion that winter groomed roads contributed to population increases of bison, or are preferentially used by bison. However, road grooming may facilitate bison movements from the interior of the park to the northern range. An adaptive management experiment could help elucidate effects of road grooming on movements of bison through Gibbon Canyon, between the Central and Northern Ranges.

- Current practices used to manage OSV use in Yellowstone have likely reduced disturbance associated with motorized winter use and access. Individual animals have been shown to respond least, both behaviorally and physiologically, to non-threatening and predictable patterns of human recreation. Humans on foot and on skis, for example, generally elicit stronger behavioral responses from ungulates than do motor vehicles on roads. Disturbances to individual animals could increase if changes in winter recreation patterns lead to more prolonged, closer, or intense interactions between people and animals, particularly if such interactions are less predictable.

- Uncertainties that may be addressed through scientific investigation.
    - Recently developed GPS telemetry technology, which permits nearly continuous monitoring of animal movements, could be used to improve understanding of cumulative effects of winter use on wildlife habitat selection, rates of movement, time budgets, and levels of activity.
    - Observational data often provide limited support for cause-and-effect inference. Spatial patterns in distribution or abundance, for example, could result from carryover effects of summer use or from characteristics of roadways rather than OSV use. Integrating experimental manipulations of OSV use could dramatically strengthen inferences drawn from studies of wildlife distribution, abundance, and activity.
    - If studies of animal movement suggest avoidance of OSV travel routes, mapping forage utilization could provide insights about effects of OSV use on availability of forage for ungulates and implications of variable use for plant communities.
    - Existing Geographical Information System (GIS) themes describing park vegetation, topography, soundscapes, viewsheds, and wildlife distributions could be used to estimate proportions of biogeographic zones and wildlife populations that are exposed to disturbances associated with OSV use. Such information could alleviate concern for some species and populations and help focus future investigations where implications for conservation are greatest.
    - For some species, limited knowledge of distribution and abundance hamper assessments of winter recreation. Indices of abundance, probabilities of occupancy, or detection rates estimated from sign surveys, camera stations, or auditory surveys could permit cost-effective, geographically extensive assessments of distribution or relative abundance.

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4.7 Appendix

Wildlife killed by collision with over-snow vehicles in Yellowstone National Park, 1989-2010

Date	Species	Road Segment
December		
12/14/93	Elk	Mammoth to Norris
January		
1/2/89	Bison	Madison to Old Faithful
1/21/89	Elk	Madison to West Entrance
1/15/93	Coyote	Madison to West Entrance
1/28/89	Bison	Norris to Madison
1/20/93	Bison	Fishing Bridge to East Entrance
1/5/97	Bison	Norris to Madison
1/27/97	Bison	Canyon to Fishing Bridge
1/26/98	Bison	Madison to Old Faithful
1/26/98	Bison	Madison to Old Faithful
1/16/98	Coyote	Madison to West Entrance
February		
2/5/89	Elk	Norris to Madison
2/6/89	Bison	Madison to West Entrance
2/26/93	Moose	Grant to South Entrance
2/17/94	Pine Marten	Canyon to Fishing Bridge
2/8/96	Coyote	Canyon to Fishing Bridge
2/3/97	Bison	Madison to West Entrance
2/4/97	Bison	Mammoth to Norris
2/10/98	Red Fox	Madison to Old Faithful
March		
3/2/03	Coyote	Fishing Bridge to East Entrance
3/2/03	Coyote	Fishing Bridge to East Entrance
3/9/03	Bison	Madison to West Entrance
3/9/03	Bison	Fishing Bridge to Grant
3/2/03	Bison	Madison to West Entrance

5. Social Science

5.1 Introduction

In this section, we review the social science literature to examine potential effects of winter use management activities on visitor experiences in Yellowstone National Park (YNP). Recognizing the potential of any action to affect visitors' experiences is of fundamental importance in managing national parks. One mandate of the NPS mission is to provide visitors with enjoyable, inspirational, and educational experiences. This becomes a complex undertaking when different visitors find enjoyment, inspiration, or education in diverse, and even conflicting, activities. In these cases, park managers may face the difficult choice of selecting between different experience opportunities. At YNP, managing winter use centers around the key questions of whether motorized use in the park by oversnow vehicles (OSVs) is appropriate, and if so, what types of vehicles should be allowed (i.e., snowmobiles, snowcoaches), how many should be permitted, and in which locations? Concerns have been raised in the past over certain aspects of OSV operation that could negatively affect visitor experiences, such as sound, odor, exhaust emissions, visible presence, and safety (National Park Service 2007b). All of these aspects can be altered to some degree by management actions. These actions, in turn, will affect visitor experiences.

Beliefs about which types of winter experiences should be prioritized in YNP are value judgments. Social science research–such as surveys, experiments, focus groups, or similar exercises–can inform decision making by measuring and describing the beliefs of visitors and other stakeholders about what is appropriate or inappropriate in the park and what is most important to each group's enjoyment and well-being. However, social science research by itself cannot substitute for public deliberation. Management decisions are arrived at in a public arena in which financial, environmental, political, and legal factors also receive consideration, and where the NPS, after considering all inputs, is ultimately responsible for making the final decision.

Numerous studies have been conducted on human values, perceptions, and behaviors in the context of winter recreational use. Over the past two decades, several of these studies have been done at YNP. In this section, the relevant social science literature, including research at YNP, is reviewed.

5.2 Impacts of OSV Management on Visitor Experiences

Managing OSV use can affect visitor experiences in YNP directly and indirectly. The NPS directly controls several elements of OSV travel, including limits on the number of OSVs in the park each day, the size of snowmobile tour groups, the relative proportion of snowmobiles and snowcoaches allowed, the grooming of roads, and requirements for visitors to employ licensed guides and use snow machines equipped with best available technology (BAT). Through these actions, the NPS also manages other aspects of OSV use that can affect the experiences of winter visitors. These aspects include factors directly associated with OSV operation, such as engine and track noise, odors, exhaust emissions, the visible presence of OSVs, and the freedom of visitors to travel where and how they like. Social scientists have addressed several aspects of visitor experiences that could be affected by OSV management at YNP. Much of the recent research has dealt with the impact of OSV noise on visitors. Information from past winter use NEPA documents for YNP (National Park Service 2007b) identified noise associated with OSV travel as a key factor that could affect specific elements of the experience of some visitors. Besides noise impacts, other potential effects on visitors of OSV use include: (1) impacts on wildlife viewing experiences; (2) impacts on preferred modes of access to the park; (3) impacts on conflicts between visitor groups; and (4) displacement of some visitors away from Yellowstone because of changes in OSV policies.

This discussion begins with an overview of social science research on the effects of noise on visitor experiences and a review of research on noise impacts specific to YNP. Following this, other potential impacts of OSV management are examined.

5.2.1. Social Science Noise Research

Soundscapes are a key element of the environment and natural ecology of national parks (Borrie et al. 2002, Bowles 1995). However, equally important are the ways in which visitors experience a natural soundscape (McCusker and Cahill 2010). Much of the social science research on soundscapes addresses the effects of noticeable natural and anthropogenic sounds on visitors' experiences in national parks and other natural areas. This has been an important area of investigation during the last two decades.

“Noise” is often defined as unwanted sound or sound that is bothersome or even physiologically harmful (Gramann 1999). This is a psychological concept that contrasts with the physical concept of “sound,” which is a fluctuation in atmospheric pressure that produces an audible sensation in the ear. Sounds become noise when they carry undesired information or hinder the perception of desired information (Blauert 1986). Once evaluated, a sound may stimulate a variety of positive or negative feelings, from pleasure or joy to annoyance to extreme irritation (Schulte-Fortkamp et al. 2007).

In a keystone summary of research regarding the effects of noise on visitors to national parks, particularly from aircraft overflights, Gramann (1999) describes three approaches that have been used to investigate the impact of sound on the public, including national park visitors. Gramann (1999) terms these the psychological approach, acoustical approach, and combination approach.

The psychological approach to soundscape research treats sound as only one aspect affecting a person’s evaluation of noise, noting that expectations, context, differences between noise decibel levels and background sounds (e.g., noticeability), and activities in which visitors are engaged when noise takes place (e.g., foreground tasks such as photography or cooking) are important factors affecting whether or not a sound is noticed and how it is evaluated. Psychological studies of these noise impacts typically lack an objective measure of sound exposure, relying instead on visitors’ self-reports of exposure to sounds they noticed.

The acoustical approach assumes physical properties of loud noise have an impact on listeners. These impacts range from annoyance, to interference with speech and the ability to hear natural sounds, to temporary or permanent hearing disorders. Acoustical studies, such as the audibility research done at YNP (Burson 2004-2009), typically do not measure visitors’ reactions to sounds. Instead, sound recording instruments or trained observers measure loudness, duration, frequency, and other sound metrics. These measures are compared to standards of acceptability derived from public input, existing standards at other areas, laws, policies, or management plans. Winter use planning at Yellowstone has adopted the acoustical approach by setting impact thresholds for sounds in developed areas, travel corridors, and backcountry areas. Exceeding these thresholds, measured in terms of A-weighted decibel levels (a unit of loudness that corresponds to how the human ear hears sounds), defines when noise from OSVs has a "moderate" or "major" impact on the natural soundscape. The advantage of the acoustical approach is that it permits soundscape management based solely on protecting a specific objectively measured sonic environment, without the additional cost of incorporating people's evaluations of noise, except as these may be used in public involvement to develop threshold levels in the first place.

The combination approach measures sound energy and immediate psychological reactions (typically annoyance level) to create a dose-response function. With this information, the researcher can describe the likelihood that a certain percentage of a population will be annoyed at a given noise dose. This analysis takes into account differing sound properties, such as frequency, rhythmic qualities, tone, and pitch. For example, in one laboratory study, subjects perceived low frequency sounds to be louder than higher frequency sounds, even when both had the same physical sound pressure measurements. This resulted in greater negative responses to the low-frequency sounds (Kuwano et al. 1989, Ozawa et al. 2003). Researchers also found that sounds that "move" in relationship to the listener's position were considered to be louder or have a "larger presence" than stationary sounds (Ozawa et al. 2003). The combination approach is expensive and logistically difficult to conduct in the field because the history of noise exposure must be quantified for visitors on the move. For this reason, dose-response research is often done in fixed locations, such as residential areas near airports or in laboratory settings.

5.2.2 Impacts of Noise on Visitor Experiences

Visitor-experience variables consist of general states (i.e., overall enjoyment) and more specific components, such as the opportunity to participate in preferred activities. Another important component of visitor experiences in parks such as YNP is the perception of the natural and human soundscapes (Freimund et al. 2009).

Previous research indicates that visual and sound stimuli interact to affect people's impressions of landscapes and soundscapes (Krog et al. 2010). One European study examined the relationship between the annoyance resulting from overhead aircraft and the annoyance associated with other problems such as crowding, road traffic noise and vehicles, and how these changes in perceived noise levels impact overall recreational experiences. Telephone interviews with recreationists were conducted between 1997-1999 in the areas of Romeriksåsen and Bygdøy, Norway (n=455 and n=591). Respondents were asked to rank their levels of annoyance with the various environmental factors: sounds from aircraft, careless bicycle riding, crowding, road traffic noise, dogs, and vehicles on forest roads, human encroachment, and seeing aircraft. The most annoying environmental factor for recreationists in Bygdøy was the sound from aircraft. Approximately half of the respondents (49.1%) found this noise to be annoying to very annoying. The second most annoying factor was careless bicycle riding, rated at 17.4%. In Romeriksåsen, similar trends occurred. Decreases in annoyance due to aircraft noise were paralleled with significant decreases in annoyance from most of the other problems. The results indicate that there is a strong relationship between aircraft noise annoyance and the overall perceived recreational quality of an area.

Noise can also raise background sound levels and the detection thresholds for other sounds. This can cause sounds that otherwise would be heard to become inaudible (Chau et al. 2010, Nilsson et al. 2010). In their study of visitors' responses to "extraneous sounds" (i.e., those emanating from aircraft, road traffic, and visitors themselves) in rural recreation areas, Chau et al. (2010) examined the proposition, supported by mounting evidence, that visitor experiences in such locations can be enhanced or degraded by natural or anthropogenic sounds. Chau et al. (2010) suggested that the positive and negative effects of these sounds are defined by the ambient surroundings, the motivations of visitors, and the context provided by the landscape. They found that high background noise levels can render extraneous sounds less audible. Moreover, the type of activities pursued by visitors also was a determinant of visitors' evaluations of noise intrusions, likely because extraneous noise can disturb or detract from the activity undertaken. Conversely, an activity can also capture the attention of visitors to such an extent that their sensitivity to extraneous noise is diminished. Visitors' negative responses were the strongest in quiet settings, and people visiting the area to hike or appreciate scenery generally had stronger negative feelings towards noise intrusions than other visitors.

The Chau et al. (2010) study illustrates how noise can mask natural sounds. Noise that distracts visitors from other sounds or causes sounds to be disregarded is termed “informational masking.” Noise that raises the threshold at which sound can be detected is termed “energetic masking” (Nilsson et al. 2010). Masking is a fully objective effect and can come from both natural and anthropogenic sources; it does not matter how the visitor feels about the noise source, or even whether they perceive and identify it.

A study by Pilcher et al. (2009) at Muir Woods National Monument offers an empirical basis for formulating indicators and standards of quality for human-caused noise in natural areas. Pilcher et al. (2009) found that anthropogenic noise can impact visitor experiences, and that these effects can be monitored using selected indicators and standards (Manning 2007). Phase one of the Muir Woods project identified potential indicators of soundscape quality important to listeners using a visitor “listening exercise.” Respondents were asked to identify natural or human-caused sounds and to rate them on a “pleasing” to “annoying” scale. Phase two of the project measured standards of quality for these indicators. Respondents listened to 30-second audio clips representing increasing amounts of visitor-caused noise and rated them on their acceptability. The results from phase one indicated that some visitor-caused sounds, such as groups talking, were more annoying than others, implying that these may be useful indicators of soundscape quality in Muir Woods. The results from phase two are significant because they used visitor input to identify thresholds for these indicators above which visitor-caused sound could be judged as unacceptable.

5.2.3 Factors that Determine Visitors’ Interpretation of Sound

People are often motivated to engage in outdoor recreation as a way to escape their busy urban lifestyles (Berman et al. 2008, Abraham et al. 2010). While in the outdoors, people are exposed to a variety of natural ambient sounds, such as those made by wind, flowing water, birds, mammals, and insects. Visitors in parks also experience anthropogenic sounds, including people talking and other human-made sounds, such as chainsaws or aircraft overflights (Kariel 1990). When noticed, some of these sounds are considered pleasing and satisfying, while others are regarded as annoying and distract from the quality of recreational experiences (Mace et al. 1999, Brambilla and Maffei 2006, Benfield et al. 2009). Interestingly, while people consistently indicate that they value natural soundscapes, available evidence suggests they are not as aware of natural sounds or impacts from human-made noise as may be supposed. For example, research reviewed by Gramann (1999) reported that about one-fifth of visitors to 39 national park units reported hearing or seeing aircraft during their visit, but only 2 to 3% reported experiencing adverse impacts from overflights.

Both Gramann (1999) and Freimund et al. (2009) found that the importance of natural sound and the impact of mechanized noise differed depending on trip motives and on the setting (i.e., frontcountry or backcountry). Gramann (1999) reported that exit interviews at 23 NPS units (National Park Service 1995) found that visitors who rated enjoying natural sounds as an important reason for their trip were more affected by aircraft noise than were other visitors. Also, a higher percentage of backcountry users than frontcountry users reported noise from overflights and were more likely to experience interference with enjoyment and natural quiet. This may be because backcountry and frontcountry visitors generally seek different experiences in national parks.

In fact, as summarized by Gramann (1999) and supported by additional research, social scientists have found that expectations about which sounds "belong" in specific environments influences listeners' level of annoyance. Brambilla and Maffei (2006) suggest that protecting quiet areas has become an increasingly significant issue, and to manage these impacts it is important to incorporate individual perceptions and subjective evaluations of these impacts, along with a consideration of the non-acoustic features of a setting that can impact experiences. The results of their experiments indicated that the expectation to hear a sound that is congruent with an urban park or rural setting impacts listeners' levels of annoyance. The more congruent a sound was with what was expected, the less it evoked annoyance. Conversely, sounds that were not perceived as acceptable in a specific setting produced higher levels of annoyance. In addition, the acceptability of the sound decreased as its detectability increased.

Researchers have found that sounds play a key role in determining environmental quality in places with a distinct environmental identity. In these situations, any non-natural or anthropogenic sounds resulted in a much lower quality rating of the landscape (Carles et al. 1999, Mace et al. 1999, Benfield et al. 2009), likely in part because it was out of context. The concept of tranquility showed similar context-specific sound and visual correlation. Tranquility was considered highest in places with more natural features and reduced sound levels (Pheasant et al. 2008), implying that visitors to natural areas who seek tranquil experiences could have the quality of these experiences reduced by non-natural sounds.

Interpretation of sound as noise can include a visual element (e.g., Abe et al. 2006, Ozawa et al. 2003). In general, people rate sounds that do not match their expectations for the environment or image pictured (e.g., truck engine sound and a picture of a waterfall) as more negative or less convincing than sounds matching the visual stimulus (e.g., waterfall sound and a picture of a waterfall). Conversely, natural sounds or visual images can also make human-made noise less intrusive or annoying. In one study, when a non-natural sound was linked to a natural image, particularly one with lush vegetation, the negative reaction to that sound decreased compared to the reaction elicited by the non-natural sound without a natural visual image (Kuwano et al. 2001). This indicates that both auditory and visual factors may be in play when visitors evaluate their experience.

Applying research findings from Kuwano et al. (2001) and similar studies, the natural visual quality at places like YNP may dampen the negative response to human-made noise. If so, this could mean that visitors are actually less annoyed by noise in the park's natural setting than in a lab because of the soothing quality of the setting itself.

In addition to the psychological and acoustical factors summarized by Gramann (1999) and others, research shows that annoyance reactions may be influenced by individual characteristics such as personality, attitudes, and noise sensitivity traits (Vastfjall 2002). Vastfjall (2002) studied annoyance with everyday noises in participants who either were slightly annoyed or in a neutral affective state. He found that individual noise sensitivity traits and current mood were important for auditory perception and evaluation.

A study by Kariel (1990) that focused on sounds in three Canadian national parks described and analyzed the relationship between visitors' evaluations of sounds commonly heard in such settings and their loudness, as measured by dBA. This study also examined other factors besides loudness related to the perception and evaluation of sounds. Kariel (1990) found that loudness alone was not a good predictor of annoyance within the range of sound levels studied. Some sounds were considered intrusive even at low levels. The author noted these results indicate that it is a combination of physical characteristics of sound and the socio-psychological characteristics of visitors which determine a sound's evaluation as pleasing, annoying, or acceptable (Kariel 1990).

As noted above, researchers agree that physical parameters of sound alone do not correlate directly with how a hearer perceives and responds. Rather, a person's evaluation of a sound depends on the information contained in the sound, the context in which it is received, and on the characteristics of the listener (Carles et al. 1999, Abe et al. 2006). Perceived sound levels and evaluations of the sound vary with place, sound frequency, expectation of hearing the sound, individual experience of the hearer, foreground tasks, perceived "appropriateness" of the sound to the setting, movement of the sound relative to the hearer (or of the hearer relative to the sound), and visual cues (Blauert 1986, Kuwano et al. 1989, Carles et al. 1999, Ozawa et al. 2003, Schulte-Fortkamp et al. 2007). These results indicate that a sound event may be evaluated by the hearer based primarily on its subjective qualities, rather than on the objective characteristics of the sound itself.

5.2.4 Noise Research at Yellowstone

One conclusion from social science research is that a majority of visitors to national parks report that they value and enjoy natural sounds, solitude, and quiet (Mace et al. 2004). At Yellowstone, much research related to winter use has focused on sustained or loud mechanical sounds from OSVs and how they are evaluated by listeners. When these sounds are evaluated negatively, it could be due to OSVs' interference with the opportunity to experience other natural and anthropogenic sounds (e.g., sounds of wildlife, thermal features, and human speech) that are important components of visitors' experiences (Burson 2004). Winter OSV noise may interfere with these experiences because the noise is distracting or because it causes people to stop listening intently to other sounds (Berman et al. 2008, Krog et al. 2010).

In their Yellowstone soundscape survey, Freimund et al. (2009) reported that most winter visitors to the Old Faithful area felt that YNP was a place for experiencing natural quiet, and that

80 to 90% of visitors (depending on access mode) stated that natural sounds played a particularly important role in the overall value of the park. In addition, experiencing natural sounds during a visit was rated as “extremely” or “very” important by 85% of cross-country skiers, 81% of snowshoers, 75% of snowcoach tourists, but only 55% of snowmobilers.

The Freimund et al. (2009) study also contains an extensive discussion of winter visitors’ views on modes of access, natural sounds, and mechanical sounds in Yellowstone. These findings come from a soundscape survey (n=413), a bison-viewing survey (n=411), and in-depth interviews with 45 winter visitors. All surveys and interviews were conducted in the Old Faithful area. Freimund et al. (2009) report that 71% of respondents to the soundscape survey said they found the level of natural sound they were looking for half or more of the time they desired it, but only 15% of visitors were able to find these experiences *all of the time* they were in the park. Still, very few respondents (8-13%) in all groups supported closing the park’s roads to all oversnow vehicles. Somewhat greater support existed for closing roads to snowmobiles, while allowing snowcoach tours to continue; but fewer than half of all groups strongly or somewhat supported this measure, and only 11% of snowmobilers supported it.

5.2.5 Effects of Natural and Human Sounds on Visitor Experiences in Yellowstone

In the late 1990s, before OSV use at YNP was managed by the NPS, Davenport et al. (2000) surveyed visitors and found most park visitors “treasured” their winter experience at the park. Visitors mentioned the landscape, geological phenomena, wildlife, and peace and quiet. Overall, they perceived management strategies, which at the time allowed unguided snowmobile use and did not require BAT, as being fair and appropriate. Visitor satisfaction at the time was high.

In another study of winter visitors during the “pre-managed era,” Littlejohn (1996) found that in response to an open-ended question about what they liked least about their visits, more respondents replied that trails and roads needed grooming (134) than that noise from snowmobiles was what they liked least (79). Borrie et al. (1998) also explored the impact of noise on the quality of the winter experience at YNP during the pre-managed era. In this study, visitors tended to describe the noise impact as neutral (neither important nor not important).

More recent studies (Freimund et al. 2009, Saxen 2008) of visitor satisfaction during the "managed era" at the park reported similar findings. These studies were among the first to provide in-depth documentation of the meanings and values that visitors ascribe to their experience of natural sounds and to address the complexity of the soundscape experience as it relates to other experiential attributes or visitor motivations. Although physical measures of the Yellowstone soundscape have been monitored for several winters, these social science studies sought to understand the human dimensions of the soundscape experience at the park by investigating the effects of noticeable natural and anthropogenic sounds on visitors' experiences. The researchers found that all of those interviewed believed the natural sounds they heard were part of what made Yellowstone special. Eighty-one percent of respondents indicated that natural sounds had a positive effect on their experience (Saxen 2008). Many said the natural soundscape assisted in providing a deep connection to nature that was restorative and even spiritual. Furthermore, natural sounds influenced respondents' motivation to visit YNP and were a significant part of the experience for over a third of visitors interviewed. Finally, winter visitors to Old Faithful generally agreed that it is a place for natural quiet and to hear natural sounds. When asked to rate Yellowstone on several characteristics, visitors tended to view the park as dominantly pristine versus polluted, quiet versus loud, and with activities that were acceptable and appropriate versus unacceptable and inappropriate (Freimund et al. 2009).

In the Freimund et al. (2009) study, the importance of the soundscape sensory experience to Yellowstone's value, to visitors' experiences, and to their support for measures to reduce motorized noise depended on primary travel mode. They reported that nearly all cross-country skiers (92%) and snowshoers (90%) in their survey thought the opportunity to experience natural sounds was important to the overall value of the park, compared to 67% of snowmobilers and 85% of snowcoach riders. In addition, 84% of cross country skiers and 81% of snowshoers believed natural sounds were equally important to their own experiences, vs. 55% of snowmobilers and 75% of snowcoach riders. When asked if Yellowstone should be a place free of motorized noise, 66% of cross-country skiers and 62% of snowshoers agreed, compared with 33% of snowmobilers and 55% of snowcoach riders. Even so, only 13% of cross-country skiers and 8% of snowshoers strongly or somewhat supported closing the park's roads to all OSVs. Snowmobilers (11%) and snowcoach riders (8%) expressed similar low levels of support. It should be noted that even cross-country skiers and snowshoers at Old Faithful depend on OSV travel to get into the park and to access trailheads.

Although the great majority of winter visitors to YNP value the park's natural soundscape, they also accept OSV access with current restrictions on numbers, snowmobile tour sizes, and with requirements for guides and BAT (Freimund et al. 2009). Similarly, visitors in the Saxen (2008) study seemed to understand the necessity of OSVs in providing access. Due to long distances (it is 30 miles from West Yellowstone to Old Faithful); visitors must use OSVs to reach major park features in the winter under the current management policies. Saxen's interviews indicated that visitors understood this tradeoff between the sounds of the vehicles they used to access the park and the natural quiet they desired to experience.

5.3 Other Impacts of OSVs on Visitor Experiences

The effects of noise on visitor experiences are not the only possible impacts associated with OSV use in YNP. Haze and odors from exhaust emissions, impacts on wildlife viewing opportunities, and safety also could be effects. These were examined in a series of studies in the 1990s (for example, Borrie et al. 1998, Borrie et al. 1999, Davenport 1999). In the post-2004 managed era, the primary park-specific winter survey focused on visitors' evaluations of opportunities to experience natural sounds and to view bison (Freimund et al 2009).

5.3.1 Impacts from Exhaust Emissions

In a survey of winter visitors conducted during the pre-managed era at the park, Littlejohn (1996) reported that 65 respondents cited pollution from snowmobiles as the part of their YNP experience that they liked least. However, this was fewer than the 79 visitors in the same survey who reported snowmobile noise as the least-liked aspect of their visit. And it was also less than the 99 respondents who said that snowmobiling was the aspect of their experience that they liked the most. Nevertheless, Littlejohn (1996) indicates that when two-stroke machines dominated snowmobile use in the park, the emissions they produced had a negative impact on the experiences of some visitors, and these were mentioned spontaneously by visitors in response to broad, undirected questions that did not prompt respondents to think about specific topics.

In their survey during the managed era, Freimund et al. (2009) found that while the impacts of management actions on the experiences of visitors are important social science issues, noise, impacts from odors, and the effects of haze were not often mentioned as problematic by the public. The evidence for this comes from the in-depth semi-structured interviews conducted by Freimund et al. (2009) with 45 winter visitors at Old Faithful. In contrast to Littlejohn's (1996) findings using similar queries, when asked undirected broad experience questions, such as "Is there anything that added to your experience today?" and "Is there anything that detracted from your experience today?" issues of haze or odor from exhaust fumes or other sources were not mentioned spontaneously by respondents. The interviews did elicit several comments about natural sound and motorized sound, but these were in response to more directed questions asked by the interviewer concerning these topics.

5.3.2 Impacts on Wildlife Viewing

As noted in other sections of this report, the interaction with natural resources, particularly wildlife viewing, has been identified consistently by researchers as an important part of the experience for the majority of winter visitors to YNP. Bison are the most visible animals in YNP during the winter season. Freimund et al. (2009) found that 71% of winter visitors to the park believed their opportunity to view bison were "very" or "extremely" important to their visit. When comparing cross-country skiers, snowshoers, snowmobilers, and snowcoach users, 70% or more of all groups rated the importance of the opportunity to view bison as very important or extremely important.

Freimund et al. (2009) also asked winter visitors about their opinions of the impact of winter use on bison. Ninety-nine percent of visitors had observed bison by the time they reached Old Faithful, and the vast majority (88%) had multiple encounters. When asked to describe the most significant or "intense" encounter with bison that they witnessed, 43% of visitors described responses no more intense than bison noticing the presence of humans and resuming their activity. Another 36% witnessed interactions in which bison appeared to be vigilant, to move away in an unhurried manner, or to have their desired movement blocked. The remaining 21% of visitors indicated seeing interactions where bison were hurried, put to flight, defensive toward humans, or appeared to fight each other as a result of human presence.

When examined by primary activity while in the park, cross-country skiers and snowshoers were significantly more likely to say that the bison they observed were “somewhat agitated,” while snowmobilers were more likely to say the bison were “very calm.” Further, snowmobilers were more likely to describe bison as “very” peaceful (67%) than were skiers or snowshoers (26%), while skiers or snowshoers were more likely than snowmobilers to say bison were “somewhat stressed” (26% versus 6%). And 60% of non-motorized users rated bison as “very” or “somewhat” dangerous, compared to 23% of snowmobilers and 47% of snowcoach riders.

Despite these differences, over 60% of all three groups evaluated their interactions with bison as “very appropriate,” indicating that most visitors did not experience interference with bison-viewing opportunities as a result of travel mode. Taken together, these results suggest that, at present levels of OSV use, visitors are likely to continue to be satisfied with their opportunities to view bison in the park, although there may be some differences in how different groups appraise the nature of these interactions.

The Freimund et al. (2009) study also included semi-structured interviews with 22 guides at YNP, nine of whom were snowmobile guides, 10 who were snowcoach guides, and three who worked with both snowmobile and snowcoach groups. Guides made several comments about the effect of best available technology (BAT) and quieter snowmobiles on wildlife and wildlife-viewing opportunities. One snowmobile guide observed that the animals had to get used to the quieter snowmobiles after being exposed to years of louder, two-stroke engines (i.e., they couldn’t hear the quieter machines approaching from as far away). Another noted that wildlife in the parks tended not to respond to the snowmobile tour groups a lot, having become habituated to them. However, this guide did mention that if he was leading a tour group on two-stroke machines outside the park, animals seemed a little more skittish about the machines. This could be because of the greater noise produced by machines with two-stroke engines versus the four-stroke machines that are required in the park under current OSV policies.

5.3.3 Safety Impacts

Impacts on visitors’ safety from changes in OSV management policies have not been studied in YNP, although some of the aforementioned results from Freimund et al. (2009) showed that cross-country skiers and snowshoers were more likely to describe bison they encountered as "dangerous" than were snowmobilers or snowcoach riders, who presumably were more protected from threatening behavior or could more easily avoid it.

Another possible effect on visitor safety of OSV management policies is the impact of increasing the number of OSVs in the park at any one time. If access is increased, more machines and more people could raise the density of use in the frontcountry. Studies in other park units indicate concerns over safety with increasing density of use, as well as correlations between use density, feelings of being crowded, and the acceptable number of encounters with others. These relationships were investigated in Yellowstone among winter visitors in the 1990s (Borrie et al. 1998, Borrie et al. 1999). This research documented variability in the number of encounters with other snowmobiles that visitors considered acceptable. How many encounters were considered appropriate depended on users' motivations for visiting YNP and on their self-reported expectations for how many other snowmobiles would be encountered.

5.4 Visitor Conflicts

Recreational use conflicts can and do arise. For example, snowmobilers and cross country skiers, hikers and off-road vehicle riders, and downhill skiers and snowboarders enjoy public lands in entirely different ways (Stevens and Frank 2009; Vaske et al. 2000). Conflicts caused by OSV use in YNP could be due to several impacts: engine or track noise interrupting inspirational visitor experiences; vehicle congestion at popular locations and rest areas; incompatible styles of use; perceived differences between user groups in social status, values, or identity; and conflicts arising from perceived differences in support or opposition to NPS management actions. In some cases, this conflict could be "symmetrical" (i.e., recognized and experienced by all groups that are involved in the conflict. In other cases, the conflict may be "asymmetrical" in that it is perceived only by the impacted group, but not by the group or groups causing the impact (Adelman et al. 1982).

A well-established definition of behavioral conflict in the recreation social science literature is "goal interference attributed to the behavior of another" (Ruddell and Gramann 1994). Goals represent preferred social, psychological, or behavioral outcomes of a behavior that provide incentive for that behavior (Gramann and Burdge 1981). According to behavioral conflict theories, when people seek certain types of experiences, but the achievement of these is interfered with by the presence or behaviors of others, conflict can result. Another definition of conflict is interference with social norms for appropriate behavior caused by the presence or actions of others (Ruddell and Gramann 1994). In addition to goal interference, violations of shared norms for a setting or activity can trigger conflicts between visitors.

Numerous studies have looked at recreation conflicts among different user types (Watson 1991, Ivy et al. 1992, Ramthun 1995, Vaske et al. 2000). For example, “trail-user conflict” is a term that has become an accepted part of the trail manager's lexicon (Dolesh 2004), describing everything from the annoyance that hikers who are seeking solitude and quiet feel when they hear a string of all-terrain vehicles (ATVs) to the very real danger when a horse and rider are startled by a mountain biker who comes up from behind in silence and without warning. Most trail conflicts that are reported happen on multiple-use trails, although some conflicts occur on unplanned, unregulated trail routes cut across public lands by ATV riders (Dolesh 2004). However, Dolesh (2004) reports that a number of comprehensive national surveys have found that, by and large, recreational trail users are satisfied with their trail experiences. Most users do not report any kind of conflicts and continue to use trails for recreation and enjoyment.

5.4.1 Noise-based Conflicts at Yellowstone

As suggested by previous noise research, the probability of conflicts arising from visitors' annoyance with motorized sounds in YNP may be highest in areas where the sounds are perceived as incongruent with the setting, such as in backcountry locations accessible only by ski or snowshoe. Expectations for experiencing tranquility, solitude, and low or zero human-produced sounds are common to backcountry users, forming an integral part of their anticipated experience and one of their primary reasons for visiting such locations (Manning et al. 2004). Research has shown that levels of tolerance for social conditions such as use density are lower in backcountry areas than in frontcountry areas of national parks and similar areas (Shelby et al. 1996). This likely extends to other anthropogenic sources of potential goal interference. Therefore, it seems reasonable to assume that motorized sounds in developed areas where visitors expect them may cause very little annoyance to users, but motorized sounds in backcountry or remote areas, especially when experienced by users who come to the park to experience tranquility, solitude, and quiet, may elicit negative reactions, including annoyance, irritation, and a lower evaluation of the overall experience (Miller 2008). If the noise interference is attributed to another group, such as OSV users, it can also trigger perceptions of conflict with that group.

Mechanized noise may be audible to humans in areas up to 10 miles from travel corridors (Hastings et al. 2006). Cross-country skiers or snowshoers, who may travel by OSV to areas inaccessible to wheeled vehicles, and then proceed on foot, would be most likely to notice such noise if they remain close to road. Though active visitors might travel beyond the range of mechanized noise, most users stay within two miles of travel corridors (National Park Service 2008), putting them well within the audible range of OSVs. If these visitors are seeking natural sound and quiet once they reach their desired destination for skiing or snowshoeing, OSV noise could result in an asymmetrical conflict in which skiers and snowshoers experience the conflict, but OSV passengers do not. Conflict could result from interference with the desire of skiers and snowshoers to experience natural sound and quiet, especially since these provide a restorative effect to many individuals, while mechanized sounds and high noise levels that are incongruent with a setting may increase visitors' stress levels (Hartig et al. 1991, Gibbons and Ruddell 1995, Booth 1999, Cessford 2000).

5.4.2 Identity-based Conflicts at Yellowstone

According to Jacob and Schreyer (1980), there are four major factors which contribute to conflict between individuals or groups in outdoor recreation: (1) differences in the level of significance attached to using a specific recreation resource; (2) differences in personal meanings assigned to an activity; (3) differences in expectations of the natural environment; and (4) differences in lifestyles. Users who become "attached" to a resource are believed to develop a sense of possession or perception of the place as a "central life interest." The degree to which a particular activity or place represents a central life interest can vary substantially among groups using an area, even among groups participating in the same activity. Thus, one individual or group may believe they are more attached to an area or an activity than a competing individual or group.

This perception is ultimately based on perceived differences between user groups and can initiate feelings of conflict with others (Jacob and Schreyer 1980).

One important cause of conflict can be the "identity" one group assigns to another. Identity, in the generic sense, consists of placing things in terms of systematically related categories (McCall and Simmons 1978). Identification in terms of broad social categories such as "snowmobiler" yields a person's *social identity*. This is distinct from *personal identity*, which classifies people into a set of categories referring to unique individuals: John and Mary Smith, the older couple from Pennsylvania who are world travelers and are making their first winter visit to Yellowstone. According to McCall and Simmons (1978), how people identify others affects their actions or inactions towards them. When strangers first interact, classification may progress from general social identity to a sharing of personal identities, facilitated by their interactions.

One of the striking features of winter use at YNP is the ease with which general social identities can be ascribed to others. Snowmobilers and snowcoach passengers not only travel through the park differently, but are observably different in other ways (e.g., snowmobilers usually wear a colorful thermal snowsuit and a helmet, with snowmobile groups wearing matching attire). Because many snowmobilers are in locations such as Old Faithful for only a few hours, their opportunity to interact with visitors staying overnight is limited. On roads through the park and at points of visitor concentration (i.e., the boardwalks at Old Faithful and Fountain Paint Pots), it is similarly easy to classify strangers as snowmobilers or snowcoach riders. This identification process, tied to mode of transport and distinctive apparel, may cause visitors to impute other differences to each other, including differences in preferred experiences, environmental values, norms for appropriate behavior, and support for NPS management policies. At times such perceived differences can form the basis for a general stereotyping of the "other." In this regard, it is possible that social groups using one travel mode could perceive a conflict with groups using another mode based on the belief that they are fundamentally different in other important ways.

Information on whether winter user groups in YNP believe they are in conflict with other identified groups in the park has not been systematically collected. Nor is it known if such conflicts (if they exist) are asymmetrical (i.e., perceived by only one group) or symmetrical (e.g., both motorized and non-motorized users equally aware of and adversely affected by the other).

Although Freimund et al. (2009) did not specifically ask visitors about conflicts in their study, they did gather information from their in-depth interviews and surveys that informs this issue. The authors noted that all visitors interviewed considered natural sounds essential to the character of YNP. This belief spanned snowmobile and snowcoach riders, cross-country skiers, and snowshoers. Although there were some differences in the relative importance groups ascribed to hearing natural sounds, the majority of all groups, including OSV users, believed natural sounds to be important to their experience. In addition, while there was a range of perspectives on the existence of mechanical sounds and vehicles in the park, all but one interviewee supported the use of snowmobiles and snowcoaches in the park with policies for BAT, guided groups, and limited group size (Freimund et al. 2009). This contrasts with an earlier study (Mansfield et al. 2008) conducted during the unmanaged era, when most snowmobiles in the park were powered by two-stroke engines. Mansfield et al. found that snowmobile riders during that period preferred the noisier (and more powerful) two-stroke machines over the quieter four-stroke engines that represented BAT. Thus, in term of support for BAT, OSV riders and non-motorized visitors during the managed era appear to be more similar than they were in the past.

Similarities continued among user groups for the interpretation of bison-human interactions at the park (Freimund et al. 2009). The primary activity that visitors engaged in did not have a strong or consistent influence on their appraisals of these interactions. Although some differences between groups existed, as noted earlier the great majority of visitors who witnessed the most intense bison responses to visitors (hurried, took flight, or were defensive) described the incidents as “somewhat” to “very” acceptable or appropriate. One explanation for many of these similarities may be that winter use now attracts a different set of visitors than when snowmobiles in the park were largely unmanaged. Therefore, mode of transport may be less associated with personal identity and related differences in attitudes, evaluations, or preferences than previously thought.

However, it is also possible that mode of travel is not the best way to segment winter visitors to assess differences between them and the potential for inter-group conflict. For example, the Borrie et al. (1999) study measured several factors for groups they classified based on their primary motivation for visiting the park in winter. These included “personal growth,” “quiet activity,” “nature study,” and “accidental.” The study found striking differences between these groups in terms of the YNP entrance they preferred, the acceptability of encounters with other OSV users, and their tolerance of difference scenarios of OSV use. However, snowmobilers made up a large segment of each group, suggesting a simple “mode of transport” segmentation may not reveal the most meaningful differences between visitors and their experiences at the park. As Davenport (1999) points out in her qualitative study of winter users, visitors are often better understood in terms of their motives and the psychological benefits they seek than in terms of their behaviors or modes of access (Driver and Manfredo 1991). This contention is reinforced by findings from a study of noise-induced conflict at Padre Island National Seashore (Ruddell and Gramann 1994). In this study, activity type was an insignificant predictor of conflict with other groups. Instead, conflict was best predicted by differences in the motives for an activity and in norms for appropriate behavior in the park. Neither motives nor norms were strongly associated with activity type (windsurfing, RV camping, fishing).

5.5 Visitor Displacement

Displacement is a coping mechanism employed by visitors in response to a sustained alteration in the character of a setting. Social scientists have hypothesized that an important force driving displacement of visitors away from a park is a sustained change in the park’s social, managerial, or environmental conditions, often evidenced by a change in the mix of user groups, support services, and facilities over time. In the case of managerial conditions, it sometimes happens that a policy change can privilege certain experiences or groups, while simultaneously displacing others (Lindberg et al. 2009, Mansfield et al. 2008).

Several studies have found evidence that some degree of displacement has occurred at many recreation locations (Anderson and Brown 1984, Becker 1981, Gramann 2002, Hall and Cole 2000, Hall and Shelby 2000, Kearsley and Coughlan 1999, Manning and Valliere 2001, Shelby et al. 1988). Hammitt and Patterson (1991) investigated coping behavior as a means of avoiding encounters among backpackers in Great Smoky Mountains National Park and found that 21% of respondents avoided trails with popular attractions and 27% avoided the park during periods of peak use (i.e., temporal displacement). Schneider and Budruk (1999) reported that 35% of respondents to a survey of lakeshore recreation areas on a southwestern national forest had changed their use of the area due to the imposition of a user fee at one of the areas. Hall and Cole (2000) found evidence of spatial displacement of visitors at a busy wilderness destination after the implementation of use limits there. The authors concluded that the new use restrictions had displaced visitors who were sensitive to regulations.

Displacement is one reason aggregate levels of satisfaction in visitor studies can remain high, even in the face of dramatic increases in crowding or other changes in a location's setting. This is because when visitor surveys are conducted, dissatisfied former visitors are no longer on site to be sampled. In addition to displacement, Shelby et al. (1988) cited another reason for this effect. According to these researchers, a second explanation for stable satisfaction levels in the face of changing conditions is "product shift," when users respond to changes by shifting their definitions of recreation experiences to conform to what is experienced. Shelby et al. found general support for product shift in a study of river users in Oregon.

Visitor Displacement at Yellowstone

The effects of management policies on different groups of park visitors is a potentially important social science issue at Yellowstone. One consequence of a change in OSV policies may be the displacement of certain groups from the park. At YNP, the current requirement for snowmobiles to be guided and equipped with BAT may have displaced some visitors, especially local residents, from winter use in the park due to the costs associated with equipment rental and guide services and the loss of freedom due to a more structured travel experience through the park. Interviews conducted when snowmobilers were able to use their own machines and travel through the park without guides found that many snowmobile users valued the freedom to set their own schedule and pace (Davenport 1999). They also appreciated the ability to interact with resources (wind and weather, wildlife, more outdoors). Supporting this, Freimund et al. (2009) reported that some OSV guides interviewed in their study felt that the guiding requirement at YNP inhibited people's freedom to experience the park on their own terms. Other guides felt that the characteristics of snowmobilers were changing, suggesting displacement of a former group of users. According to these guides, more snowmobilers were coming to YNP to experience the park on a snowmobile rather than using the park to experience a snowmobile.

However, other guides commented that most visitors were making their first winter visit to the park and were unaware of the context of the regulations, and simply accepted the rules as they found them. Loss of freedom and preferred experiences because of the guide and BAT requirements did not appear to be an issue for these visitors, since first-timers lacked a basis for comparison.

Additional evidence that residents of the region bordering Yellowstone are the most likely to have experienced displacement due to changes in OSV regulations comes from a study by Duffield and Neher (2000). In their survey of the willingness of Montana, Idaho, and Wyoming residents to pay for winter experiences at YNP under different management policies, Duffield and Neher found that only 49% of residents would continue to visit the park if the costs associated with BAT increased by $100 per visit. In contrast, 88% of nonresidents said they would still visit, even with increased costs.

It is also possible that less regulation of OSV technology and numbers in the early 2000s displaced visitors seeking quieter or more primitive conditions in the park (Mansfield et al, 2008). However, the little research that has been conducted on this impact has been inconclusive.

Although the NPS has some information on displacement, no systematic study of this impact has been conducted in the managed-use era. Gathering unbiased information is challenging, but has been done in other contexts. This could involve specially designed household surveys, focus groups in targeted areas where displaced populations are known to reside, or key informant interviews with representatives of displaced populations.

5.6 Controversy Over Management Actions

Controversy over snowmobile use in YNP has led to a succession of winter use policies that have differentially affected various groups, leading to differences in their stances on these policies. During the pre-managed era in the late 1990s, visitors were asked about their support for new management actions, including requirements for BAT and limiting the number of OSVs in the park. At that time, when few restrictions on OSV use were in place, researchers found little support for the proposed policies (Borrie et al. 2002). Subsequent in-depth interviews by Davenport (1999) revealed that when it came to management actions that were justified as protecting wildlife in the park, visitors did not perceive the need for such actions or believe that wildlife protection was an issue. Most had seen bison placidly standing on or near the roads in the park, apparently unaffected by OSVs (wildlife monitoring at the time indicated that less than 10% of bison displayed more than a "look and resume" reaction to OSVs).

In 1999, during the pre-managed era, Davenport and Borrie (2005) conducted 65 semi-structured interviews with snowmobilers to find out their perspectives on the appropriateness of their activity in the park. The researchers addressed two topics in the interviews: (1) does snowmobiling in national parks cause unacceptable biophysical and social impacts? and (2) are snowmobiling experiences consistent with the fundamental purposes of national parks? Davenport and Borrie (2005) found that YNP visitors on snowmobiles did not perceive the activity as their primary objective, but merely a mode of transportation to view the various wildland attributes possessed by the park (natural scenery, geothermal activities, and especially, the wildlife). According to snowmobilers, their activity offered a sense of freedom and provided highly meaningful recreational experiences within the park, including the opportunity to appreciate the park's many unique features and attributes. The researchers concluded that visitors who seek to enjoy the park's attributes via snowmobile could find it difficult to substitute these experiences if snowmobile use were limited or eliminated.

In another study conducted during the pre-managed era, Mansfield et al. (2008) showed that various winter use management policies in YNP can impact park visitors' welfare. This 2003 survey used a stated-preference choice experiment to determine visitors' preferences for winter management in YNP and Grand Teton National Park, and to determine welfare changes for both snowmobilers (owners and non-owners) and non-snowmobilers under various snowmobile restrictions. Three scenarios were given for snowmobile management: (1) requiring riders to be guided; (2) reducing the number of snowmobiles in the park (potentially to zero) and; (3) requiring technological restrictions (BAT). The survey results indicated that non-snowmobilers were attracted most to policies that were the most damaging to snowmobilers. Additionally, snowmobile owners suffered disproportionally from technological restrictions (4-stroke engines), since under the proposed policy on BAT, they could no longer enter the park with their private machines, but would be forced to rent one. Snowmobilers' welfare losses could be offset by net gains to non-riders or individuals who were willing to trade off activity choices for an improved natural ambient environment within the park. Overall, their results indicated that some restriction on snowmobile access was likely to improve overall welfare, but they also noted that the details of how use is restricted matters substantially, as they would impact some users more than others. They concluded that the aggregate impact of any restrictions ultimately would depend on the number of each type of visitor and how the mix of visitor types changed in response to a new policy.

Later surveys conducted during the managed era found visitors' opinions on many OSV management policies had changed (Freimund et al. 2009). Overwhelmingly, winter visitors surveyed in 2008 supported elements of the current OSV management (i.e., BAT and guiding), but disagreed with proposals to plow roads and ban snowmobiles from the park entirely. Even snowcoach riders, cross-country skiers, and snowshoers did not support banning snowmobiles completely. When asked whether roads groomed for OSV use should be plowed for wheeled vehicles instead, 79% of those using OSVs in the park were either against or strongly against this change.

Taken at face value, these results from two different eras suggest that most park visitors are satisfied with whatever current conditions and management actions exist at the time. However, the opinions of non-visitors and displaced visitors are not included in these findings. Public scoping or comments on winter use planning documents, as well as anecdotal information, are the current primary sources of knowledge regarding the opinions of those who either choose not to visit or who may have been displaced by management actions.

5.7 Economic Impacts of Winter Use Activities

The economic impacts of visitation to national parks are significant (Duffield and Neher 2000, Stynes 2005). For example, in 2009, spending in the area around YNP by non-local visitors to the park amounted to $297 million, supporting almost 4,400 jobs (Stynes 2011). In terms of winter use at the park, Duffield and Neher (2006) examined the potential economic impact of different winter use management policies at progressively finer levels of regional analysis, including impacts on: (1) the three-state region (Wyoming, Idaho, and Montana); (2) the five-county area around Yellowstone and Grand Teton national parks; and (3) the gateway communities of West Yellowstone, Montana, Jackson, Wyoming, and Cody, Wyoming. The authors noted that, in response to previous changes in winter use policy, one of the major effects at YNP between 1996-97 and 2005-06 was a reduction in total snowmobile use and the substitution from snowmobile use to snowcoach use. Between 2001-02 and 2005-06, snowcoach visitation to YNP increased at an approximate 10% to 13% rate annually, while snowmobile entries into the park dropped from a peak of 87,206 in 2001-02 to 28,833 in 2005-06. The area most impacted by policy changes was the gateway community of West Yellowstone. According to the authors, in response to significant reductions in winter park visits through the West Yellowstone Entrance in 2002-03 through 2005-06, resort tax collections in that community also fell. However, the decline was not in proportion to the decrease in West Entrance visits. Specifically, comparing average levels for the four years after management changes (2002-03 through 2005-06) to the four years immediately preceding the changes showed that while park visitation through the West Entrance fell 48.5% on average, winter tax collections fell only 19.7%. One reason for this could be substitution of snowmobiling in the Hebgen District of the Gallatin National Forest for snowmobiling in YNP. The district includes many miles of groomed snowmobile trails that are accessed primarily from the West Yellowstone area. However, the limited data that existed at the time suggested that restrictions on snowmobile access at the West Entrance did not lead to increased use on the adjacent national forest. The authors also pointed out that other factors, notably drought and reduced snowpack, had significant impacts on winter use in the area. Finally, Duffield and Neher (2006) noted that even small changes in economic activity as a result of new winter use policies at YNP would occur during the relatively short winter season and thus would disproportionately affect businesses and employees who rely on winter visitors for a large share of their annual income.

Coupal et al. (2001) conducted an economic valuation study of snowmobiling in Wyoming. While not an analysis of the economic impact of the activity, their study did estimate the value that snowmobile owners placed on their activity. Coupal et al. (2001) employed cluster analysis to identify various snowmobile segments and used the travel cost method to estimate the consumer surplus values for the pooled sample and the various snowmobile segments. In this case, consumer surplus is the difference between the total amount snowmobilers would be willing to pay for their trip and the amount they actually spent. If snowmobile owners will pay more than the current asking price, then they are getting more benefit from a trip then they spent to purchase it.

Coupal et al. (2001) mailed questionnaires to 1,544 registered snowmobile owners in the state of Wyoming. Survey questions were designed to elicit information on trip costs, trip behavior, reasons for travel, substitute sites, and demographic information. Research results implied that consumer surplus per trip for the pooled sample was $68. For the various market segments, the values ranged from $31 to $101 per trip, depending on the segment. Results from the pooled model and the segmented models suggest two implications: (1) the heterogeneous nature of snowmobilers in Wyoming implies that benefit estimates could vary considerably across participants at a single site and across different sites; and (2) targeting policies and programs to specific groups could significantly increase the benefits of a recreation activity or recreation area, therefore increasing the value of the public places through programs that attract recreationists. The differences between the pooled model and segments emphasize the need for differentiating recreation users in a single activity for both economic benefit measures and management-related issues.

National Park Service (2005) also conducted an economic valuation of winter use management alternatives in YNP. Similar to Coupal et al. (2001), this analysis also estimated consumer surplus values. Using a stated preference method called conjoint analysis, the authors estimated that if snowmobile riders did not visit YNP due to a ban on snowmobiles, their utility would decline by $191 per trip. The same ban, on the other hand, would increase the utility of non-snowmobile riders by $437 per trip. One possible explanation for the large disparity in the magnitude of impacts between snowmobile riders and non-snowmobile riders is that the conjoint analysis was set up as a day trip model and it appears that on any given day during their multi-day trips, snowmobile riders prefer snowmobile use outside YNP to snowmobile riding in YNP. However, snowmobile riders may still place a high value on being able to visit YNP as part of their visit to the greater Yellowstone area. Without the ability to snowmobile in YNP, many riders may choose to travel to another area away from the park. Thus, the loss estimated for banning snowmobile use may understate utility losses by focusing on the losses for a given day.

5.8 Other Regional Considerations

The impacts of winter use management at Yellowstone are not confined to the park's visitors and former visitors. Park management actions at major tourist destinations such as YNP can also affect people living in regions around parks. As already discussed, one possible impact is on those who depend on winter tourism for their livelihoods. But other impacts on individual lifestyles and communities could occur. The NPS recognizes the importance of this interaction between parks and neighboring communities and recognizes the critical role of ongoing dialogue with these publics in addition to seeking their input in formal planning processes (National Park Service 2001, 2007a). In fact, initiatives in the Greater Yellowstone Ecosystem (GYE) recognize YNP as one component of a broader and integrated social and environmental landscape.

Reading and Clark (1994) suggest that ecosystem management has gained greater significance in the management of the Greater Yellowstone Ecosystem (GYE) as a result of growing concerns over threatened resource integrity. This has resulted in increased coordinated management in the region. Reading and Clark (1994) argue that successful management of this region needs to acknowledge and incorporate local populations' knowledge and attitudes about the area, management strategies, and economic impacts. To gauge local opinion about management issues in the GYE, the researchers surveyed 308 randomly selected residents through in-person and telephone interviews. Using principal components and factor analysis, three attitude scales were created: (1) ecosystem management (strong support for ecosystem management and wildlife); (2) utilitarian (strong support for direct utilization of natural resources); and (3) libertarian (strong support for individual rights and freedoms in the GYE). Three-quarters of respondents believed that ecosystem management within the GYE was necessary to prevent harmful impacts. However, the majority were opposed to any restrictions on visiting national parks such as Yellowstone to protect the GYE. Younger residents were more supportive of ecosystem management, as were respondents from larger towns. Respondents from small, rural communities scored significantly higher on the utilitarian and libertarian scales. Additionally, those landowners who owned more land also scored higher on the utilitarian and libertarian scales. Results indicated that residents new to the area, or who were dependent upon tourism for income, scored higher than locals on the ecosystem management scale. Much of the local concern (which was characterized with strong libertarian and utilitarian values) over ecosystem management was related to governmental control and economic issues. The authors concluded that despite the recent economic shift from resource exploitation to a tourism-based region, the historical background based in agriculture and resource-extraction strongly shaped current attitudes towards management in the GYE.

5.9 Monitoring Policy Impacts

Monitoring is "the collection and analysis of repeated observations or measurements to evaluate changes in conditions and progress toward meeting a management objective" (Elzinga et al. 1998). Monitoring requires institutional continuity, long-term planning horizons, stability in methods and samples, and predictable commitments of funding and staff. This ensures that, over time, monitoring protocols will continue to meet defined standards of quality, adequately characterize uncertainty, and usefully measure change along socioeconomic gradients (Gramann et al. 2010).

In the NPS, the Visitor Experience and Resource Protection (VERP) framework is one approach to monitoring the impacts of management actions, such as changes in winter use policies at YNP, on visitors' experiences (National Park Service 1997). The VERP process describes a potential range of visitor experiences, selects indicators of these, develops standards for each indicator (these may vary in different park zones), and monitors indicators over time to determine whether standards are being exceeded. Often, identifying indicators and specifying standards involves public input, as does monitoring itself. This includes identifying public norms for different standards of experience quality by asking visitors to judge the acceptability of a range of impacts to natural and cultural resources and the quality of visitor experiences (Laven et al. 2005). In the NPS, a common example of this approach is the identification of standards for crowding, including the number of people and vehicles in a setting (Manning 2007). According to Krymkowski et al. (2009), normative theory and methods have become increasingly important in outdoor recreation research and management as a way to gain public input into the formulation of quality standards for visitor experiences.

An important issue associated with the normative approach is the level of agreement or consensus among different groups about what is appropriate or inappropriate in a setting. Kuentzel et al. (2008) explored variation in normative standards at 52 locations in 13 national park units. Their analysis indicated that the prevalence, importance, and stability of normative standards can vary across different settings and activities. Another review by Laven et al. (2005) examined research in 11 national park units between 1995 and 2002 found that visitor-based standards of quality were generally unrelated to existing conditions in the park. This argues against the notion that, when judging quality standards, visitors simply reify existing conditions as they find them.

An important step in the VERP process is identifying the range of experience opportunities that should be provided. Without this, indicators and standards cannot be developed and monitoring the achievement of management objectives cannot proceed. This approach, along with other indicators of visitor experience, were explored in Yellowstone in the 1990s (Borrie et al 1998 and Borrie et al 1999) as part of applying the NPS VERP concepts to Yellowstone winter use (Greater Yellowstone Coordinating Committee 1999). Although public feedback on norms can inform this process, many other inputs exist. The 1872 enabling legislation for Yellowstone National Park, as well the 1916 act that created the National Park Service, specify that one broad experience at Yellowstone should be "enjoyment." In addition, a suite of objectives for the winter use plan have been identified. In the 2000 winter use plan, and in subsequent winter planning processes, the NPS VERP concepts continue to be applied through the development of alternatives (experience opportunities) and implementation of monitoring and indicators and standards.

Potential social and economic impacts of winter use management have been described in previous sections of this report. These include sensory impacts on the experience of the park's natural soundscape and landscape, effects on wildlife viewing opportunities, impacts on the safety of visitors and their perceptions of conflict, displacement from the park due to cost and loss of preferred experiences, and economic impacts on gateway regions. In one form or another, each of these potential impacts relates to an objective of the YNP winter use plan. An important task will be to identify measurable indicators and quality standards that can be monitored to determine if the plan is achieving its objectives.

5.10 Conclusion

This chapter reviewed potential social and economic consequences related to direct impacts from OSVs (noise, visible haze and odors from exhaust emissions, impacts on wildlife viewing opportunities, and safety) and other potential consequences of OSV management policies (visitor conflicts, visitor displacement, controversy over management actions, economic impacts of winter use, other regional considerations, and monitoring needs). For each of these areas, key findings and research needs are summarized.

- In terms of direct impacts from OSVs, a large body of literature addresses the role of noise in evaluation of visitor experience in recreational settings, applying either a psychological approach, acoustical approach, or a combination approach. Winter use plans at Yellowstone has adopted the acoustical approach, which has the advantage of relying on a specific objectively measured sonic environment. Yet, numerous studies indicate the importance of subjective qualities in the evaluation of sounds by visitors. Context, expectations, visual cues, foreground tasks, and trip motives are some of the factors that have been shown to affect evaluation of sounds as noise.

- Studies conducted in YNP corroborate the importance of natural sounds on visitor experience, and for the most part indicate that visitors have been satisfied with their soundscape experience, both before and after the managed-use era. Although studies have found that the importance of the soundscape sensory experience to Yellowstone's value, to visitors' experiences, and to their support for measures to reduce motorized noise depended on primary travel mode, other studies indicated that visitors understood the tradeoff between the sounds of the vehicles they used to access the park and the natural quiet they desired to experience. Studies consistently report low support for closing the park's roads to all OSVs, regardless of primary travel mode.

- While studies generally report low effects from OSV noise on visitor experience, especially during the managed-use era, additional research could provide information on more specific elements that factor into subjective evaluation of OSV noise at YNP. Specifically, a dose-response study in the field would help social scientists and the park understand the level of noise exposure and effects in a typical winter. Objective measures from noise monitoring results would be correlated with visitors' evaluations of sounds and analyzed by context, expectations, and other factors that may affect experiences. A similar study in a laboratory could help determine the relationships between audibility or annoyance and the number of OSVs, effects of snowcoach BAT, and impact of OSVs (visual and noise) on hearing and appreciation of natural sounds or landscapes. The restricted generalizability of laboratory experiments to field conditions is compensated for by the greater control in lab settings over the variables being tested. Together, both laboratory and field studies would contribute to a more complete understanding of the impacts of OSV use on winter use experiences. In some cases, as the Muir Woods soundscape studies indicate (Pilcher et al. 2009); it is possible to adapt laboratory methods and controls for use in field settings. Finally, noise monitoring could be modeled in GIS to create a "noise exposure surface" that could be compared to a study of visitor flows through YNP. This type of analysis can yield an objective measure of visitor noise exposure across the landscape, which could then be compared to results from the dose-response studies.

- With respect to potential impacts from other aspects of OSVs on visitor experience, visible haze and odors from exhaust emissions, impacts on wildlife viewing opportunities, and safety were reviewed. When two-stroke machines dominated snowmobile use in the park, the emissions they produced had a negative impact on the experiences of some visitors, yet issues of haze or odor from exhaust fumes or other sources were not mentioned spontaneously by respondents in studies conducted in the managed-use era. While studies have not been specifically designed to assess visitor evaluations of objective measures of emissions (e.g., human dimensions of OSV emissions), national standards for air quality and emissions may serve as adequate proxies, given that visitors did not identify issues related to exhaust emissions when air quality considerations were being managed.

- Studies related to wildlife viewing have focused on visitor perceptions of bison viewing opportunities and bison activity. The opportunity to view bison was rated as important to most visitors, regardless of primary mode of transportation. At present levels of OSV use, visitors are likely to be satisfied with their opportunities to view bison in the park, although there may be some differences in how different groups appraise the nature of these interactions. Studies have not examined the degree to which opportunities to view other types of wildlife in the park factor into visitor evaluations of their winter experience.

- In addition, few studies have specifically examined safety impacts from changes in OSV policies. Given that studies in other park units have indicated concerns over safety with increasing density of recreational use, as well as a correlation between user density and the feeling of being crowded, a similar study in YNP could be warranted if access is increased or group size and/or spacing between groups is managed.

- In addition to direct impacts from OSVs, managed winter use also can result in conflicts that affect visitor experience. In the context of winter use at YNP, noise-based conflicts and identity-based conflicts were identified as potentially most salient. Noise-based conflicts have not been explicitly studied at YNP, although they could be addressed as components of the broader noise studies suggested above. Similarly, information on identity-based conflicts between winter user groups in YNP has not been systematically collected. Researchers have noted that OSV management policies impact (or privilege) some users more than others. Better understanding the degree to which these differential impacts contribute to conflicts between user groups would help managers identify and address potential points of controversy. Further, additional studies that focus on visitor motives, the psychological benefits they seek, and norms of behavior as alternate ways to segment the public may help identify drivers of conflict that were previously overlooked.

- Changes in management policies not only can privilege some experiences or users, they also can displace others. Visitor displacement has been documented in many recreation locations, and is one reason aggregate levels of satisfaction in visitor studies can remain high, even in the face of dramatic changes in the nature of a setting. The review of controversy over management actions noted that studies from the unmanaged-use and managed-use eras appear to suggest that most park visitors are satisfied with whatever current conditions and management actions exist at the time, but that inclusion in these studies of non-visitors or displaced visitors could have brought a different perspective. Similarly, studies of economic impacts document the substitution from snowmobile to snowcoach use in response to changes in management policies and also suggest some snowmobile activity may be displaced to other nearby public lands. The little research on displacement that has been conducted relative to winter use at YNP has been inconclusive, and no systematic studies have been conducted in the managed-use era. However, there is value in understanding displacement of visitors or locals due to implemented management actions such as OSV or BAT requirements, as well as the consequences of displacement and potential substitutes (both in areas outside YNP or to different activities within YNP). This could be examined systematically at local, regional and national levels through interviews with key informants, community surveys, or even small-scale experiments within an adaptive management framework.

- In addition to current and displaced visitors, the impacts of winter use management at YNP also can affect people living in regions around the park. Potential impacts include economic impacts to those who depend on winter tourism for their livelihoods, as well as impacts to individual lifestyles and communities. While researchers have argued that successful management of this region needs to acknowledge and incorporate local populations' knowledge and attitudes about the area, management strategies, and economic impacts, few regional studies have been conducted. While some original research on the economic impacts and valuation of winter use in YNP has been conducted (Duffield and Neher 2006; National Park Service 2005) additional research on these topics could help inform assessment of regional impacts from management actions.

- The potential social and economic impacts of winter use management examined above relate to objectives of the YNP winter use plan: (1) provide the opportunity for visitors to experience and be inspired by Yellowstone's unique winter resources and values while ensuring resource protection; (2) increase visitor understanding and appreciation of the park's winter resources; and (3) provide access for winter opportunities in the park that are appropriate and universally acceptable (NPS 2010). Further, the park seeks to manage access in the winter for the safety of all visitors and employees, including limiting impacts from emissions, noise, and known hazards. A final objective is to improve coordination and communication regarding winter use management with park partners, gateway communities, and other stakeholders. To fully determine the degree to which these objectives are met, each of the objectives must be operationalized to identify measurable indicators and quality standards that can be monitored.

5.11 References

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