Air Quality Concerns Related to Snowmobile Usage in National Parks

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Background

National Park Service (NPS) regulations (36 CFR Part 7 and 36 CFR Part 13) allow snowmobile use in more than 40 of the 378 units of the National Park System (see Appendix A, Table 1). The amount of use, and associated impact, varies greatly among units. For example, in the winter of 1998-1999, only about 10 snowmobile groups entered Mount Rainier National Park (NP). On the other end of the spectrum, during the same time period, more than 76,000 tourists visited Yellowstone NP on roughly 63,000 snowmobiles, with nearly 54,000 visitors travelling via a single corridor from the West Yellowstone entrance in Montana. There are various environmental and health impacts associated with the use of snowmobiles in national parks, including air quality impacts from exhaust emissions. The Bluewater Network, a coalition of environmental organizations, has petitioned the NPS to ban snowmobile use in units of the National Park System. The NPS is currently considering the petition. The intent of this paper is to present information regarding the potential air quality impacts associated with snowmobile use in national parks. This information, in conjunction with other available information, will enable the NPS to make informed decisions regarding the use of snowmobiles in units of the National Park System.

This report summarizes available information and reports related to the air quality impacts of snowmobiles. It is necessarily limited by the scope, methods, and content of the studies cited. It provides a general overview of highly complex technical data. Although it relies heavily on information obtained from studies conducted at Yellowstone NP, it is not a complete compendium of the extensive studies that have been conducted there and in other areas. The comparisons made using Yellowstone data could be viewed as a high use scenario and apply only to Yellowstone. However, the results from Yellowstone demonstrate the impacts on air quality that may result from heavy snowmobile usage in an area. As the popularity of the sport grows, so will the potential for air quality impacts on park resources, as will the need for park managers to carefully consider these impacts in their decisions.

Snowmobile Emissions

Snowmobiles use two-stroke engines, in which induction of fresh fuel and expulsion of exhaust take place simultaneously through openings in the cylinder. For a number of reasons, two-stroke engines emit substantial amounts of air pollutants. First, up to one-third of the fuel delivered to the engine goes straight through without being burned. Second, the lubricating oil is mixed with the fuel, and thus is expelled as part of the

[1] This is a revision of an October 1999 report. Appendix B discusses the changes between this report and the previous version.

exhaust. Third, the combustion process results in high emissions of air pollutants. In addition, snowmobiles and other gasoline-powered motor vehicles emit several pollutants, such as benzene, 1,3-butadiene and gas-phase and particle-phase polycyclic aromatic hydrocarbons (PAHs) that the U.S. Environmental Protection Agency (EPA) classifies as known or probable human carcinogens. EPA estimates that mobile sources account for as much as half of all cancers attributed to outdoor sources of air toxics (U.S. EPA 1994a). Although “air toxics” can be defined simply as air pollutants that cause adverse health effects, in the context of this report they mean toxic organic compounds. Emissions of air toxics from snowmobile engines were found in significant amounts and in proportions similar to those found in gasoline-fueled passenger cars in testing performed by Southwest Research Institute (SwRI) (White and Carroll 1998). Numerous air toxics are also present in diesel exhaust, which contains over 40 substances that are listed by EPA as hazardous air pollutants and by the California Air Resources Board as toxic air contaminants (California Air Resources Board 1998).

There are various sources of information on snowmobile emissions with the most recent being those prepared for the State of Montana Department of Environmental Quality and the International Snowmobile Manufacturers Association by SwRI (White and Carroll 1998) and for the Yellowstone Park Foundation (Carroll and White 1999). Table 1 below lists these emission factors and compares them with factors previously published by EPA and the California Air Resources Board. There is some variability in these factors due primarily to the test procedure used on the engines, the fuels used, and the engine lubrication oil. As also shown in Table 1 below, four-stroke engines emit substantially less hydrocarbons (HC) and particulate matter (PM), about the same amount of carbon monoxide (CO), but more nitrogen oxides (NO_x) than 2-stroke engines. However, 4-stroke engines are virtually non-existent in today’s snowmobile market. And although there are efforts to develop a clean snowmobile, there are no current regulations driving the development and widespread use of these engines. Similarly, the introduction of lower-emitting, direct-injection 2-stroke engines in snowmobiles will likely not occur quickly because there are no current regulations requiring the reduction in emissions from snowmobiles.

When compared to various automobile emission estimates, a snowmobile operating for 4 hours, using a conventional 2-stroke engine, can emit between 10 and 70 times more CO and between 45 and 250 times more HC than an automobile driven 100 miles (see Appendix A, Table 4). A similar comparison of results from tests also conducted by the University of Denver (DU) showed HC and CO emission factors from snowmobiles to be about 80 and 7 times greater, respectively, than emission rates for the 1995-1996 Denver automobile fleet (Bishop *et al.* 1999). However, when one takes into account the difference in fuel efficiency between snowmobiles and automobiles, the ratios calculated using the Bishop *et al.* factors are very similar to those cited above. There are many reasons for the difference in these ratios, including the use of different testing methods and procedures. The variability in these factors between and within tests underscores some of the uncertainty in determining the actual emissions from the various source categories. This is true for emission factors for automobiles as well as other mobile sources.

As with automobiles, emissions of HC, CO and PM can increase if snowmobile engines are not properly tuned for local conditions. The "SwRI 98 Polaris Rich" test (see Table 1 below) was conducted to simulate emissions from snowmobiles that are tuned for lower elevations but used in higher elevations, such as Yellowstone. University of Denver results also showed a wide range in CO emissions depending on engine manufacturer and between fan-cooled and liquid-cooled engines. Unlike automobiles, where a relatively small number of older cars emit at much higher rates than newer cars, snowmobile emissions tended to be more clustered around the mean and were approximately normally distributed.

Table 1. Snowmobile Emission Factors

Source of Emission Factor	*Emission Factor, grams/hp-hr*			
2-stroke engines	**HC**	**NO_x**	**CO**	**PM**
1. EPA NEVES, 1991	228	1.7	321	4.8
2. EPA, 1999	154	0.5	390	2.4
3. CARB	109	1.7	169	4.8
4. SwRI 98 Polaris Base	151	0.4	416	1.3
5. SwRI 98 Polaris Rich	180	0.3	474	1.7
6. SwRI 98 Polaris Gasohol	127	0.4	377	1.0
7.SwRI 98 Polaris Gasohol/Bio Lube	104	0.4	332	1.7
8. SwRI 98 Polaris Aliphatic	201	0.5	424	2.0
9. SwRI 98 Arctic Cat Gasoline	156	0.5	363	3.5
10. SwRI 98 Arctic Cat Gasohol	164	0.5	342	3.4
11. SwRI 99 Polaris BASE	116	0.7	376	0.7
12. SwRI 99 Polaris BIO	120	0.7	391	1.4
4-stroke engines				
13. EPA 4-stroke overhead engine	5.2	3.5	409	0.04
14. CARB 4-stroke <= 25 hp	4	1.8	240	0.09
15. CARB 4-stroke >25 hp	2	3	150	0.00

1. Nonroad Engine and Vehicle Emission Study, U.S. EPA Report No. 21A-2001, 1991
2., 13. Exhaust Emission Factors for Nonroad Engine Modeling—Spark Ignition, U.S. EPA Report No. NR-010b (EPA420-R-99-009), 1999
3. California Air Resources Board (as reported by U.S. EPA in Exhaust Emission Factors -- Spark-Ignition, NR-010a (revision posted 6/19/98)—"compare.xls")
4-10. *Emissions from Snowmobile Engines using Bio-based Fuels and Lubricants*, White and Carroll, 1998
11-12. *"Characterization of Snowmobile Particulate Emissions,"* Carroll and White, 1999
14-15. Emission Factors files (*.emf) used for Nonroad model at: http://www.epa.gov/oms/nonrdmdl.htm

In a similar study conducted by DU in the winter of 1999 to investigate the effects of oxygenated (ethanol-blended) fuels on snowmobile emissions, the results showed that a reduction in CO of 7 $\pm$ 4% could be achieved in Yellowstone using oxygenated fuels. However, oxygenated fuels did not appear to reduce HC emissions. This study also attempted for the first time the real-time remote sensing of toluene, a component of gasoline. Results from data collected at the West Entrance station over a 2-day period showed a mean toluene concentration of 1976 ppm in snowmobile exhaust (Morris *et al.* 1999). The toluene to HC ratio measured in this study was consistent with toluene content of non-oxygenated fuels.

Snowmobile emissions within a national park will vary based on numerous factors. These factors include the number of machines entering the park, the number of hours used, the type of engines and fuels used, engine speed, elevation, and ambient temperature at which the machines are operated, and how well the engines are tuned. In general, emissions increase with an increase in engine speed (rpm); direct-injection 2-stroke and 4-stroke engines emit less HC and PM than conventional 2-stroke engines; and oxygenated fuels can reduce the levels of certain pollutants. Carbon monoxide emissions decrease with decreasing temperature because the mass of oxygen will increase for a given volume of air at lower temperatures. Also, as the air/fuel ratio decreases from stoichiometric the formation of CO increases due to the decrease of oxygen (Morris *et al.* 1999).

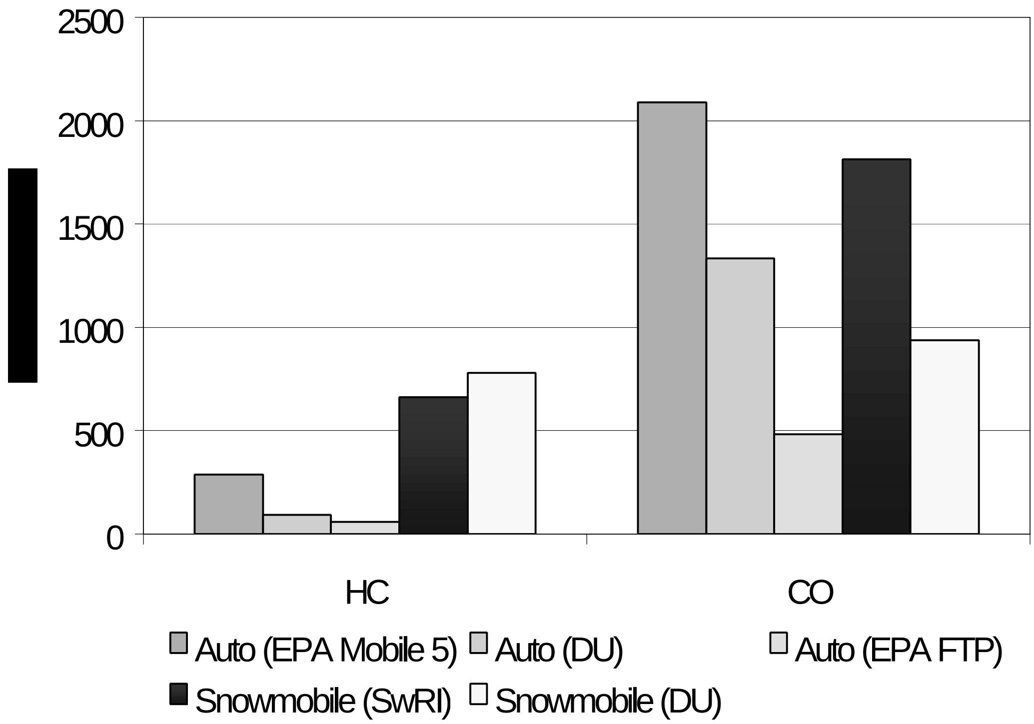
Yellowstone National Park: An Air Pollution Emissions Case Study
The use of snowmobiles at Yellowstone has grown substantially over the years. Since 1992 snowmobile use was highest in 1993 when more than 77,000 snowmobiles entered the park. In 1999 (December 1998 – March 1999) 62,878 snowmobiles entered the park, which is less than the average of 66,619 snowmobiles that entered the park between 1992 and 1999.

The snowmobile season lasts approximately three months at Yellowstone NP from mid-December through mid-March. Table 3 of Appendix A provides vehicle count statistics for the period 1992-1999. Vehicle count and emission factor information can be used to estimate total annual emissions for the different types of vehicles entering the park. Although the number of snowmobiles is on average a factor of 16 lower than the number of automobiles entering the park annually (1,075,295 cars *vs.* 66,619 snowmobiles), snowmobile emissions can equal or exceed total annual emissions for CO and HC from other mobile sources (*i.e.*, cars, RVs, buses and snow coaches). Depending on which emission factors and assumptions are used, estimates for total emissions from different mobile sources can vary substantially. Figure 1 below shows how this variability in emission factors influences estimates of total emissions for HC and CO from automobiles and snowmobiles. From Figure 1 below, one also notes that total estimated HC emissions based on SwRI and DU emission factors are similar but there is a factor of 2 difference in estimated CO emissions. Also one notes that EPA's Mobile 5 emissions model results in substantially higher HC and CO emissions than those using either EPA's 1996 model year certification standards (EPA FTP) or the DU remote-sensing measurements for the Denver automobile fleet. This report does not attempt to reconcile the differences noted.

As shown in Table 2 below, the contribution from snowmobiles to total annual HC emissions from all mobile sources can range from 68% to 90% at Yellowstone depending on which emission factors are used to estimate emissions. Similarly, snowmobiles can contribute from 35% to 68% of total CO annual emissions. These estimates are based on the assumptions that each snowmobile is operated on average for 4 hours at 16 horsepower (hp) (or consumes 11 gallons of fuel per visit) and snow coaches travel an average of 100 miles per visit. Cars, buses, and RVs are assumed to travel 120 miles during each visit to the park. Snowmobiles are estimated to contribute about 2% and

39% of annual NO_x and PM emissions, respectively, at the park. Although the numbers of snow coaches and buses entering the park annually average 1,400 and 5,800, respectively, emissions from these vehicles are estimated to contribute on average 1% or less of CO and HC annual emissions (see Appendix A, Tables 5 and 6).

Figure 1. Comparison of estimated annual HC and CO emissions at Yellowstone National Park based on various emission factors for automobiles and snowmobiles.



Using SwRI's emission factors, as much as 765 tons of HC and 2,100 tons of CO can be emitted in a single season (1993) at Yellowstone (see Appendix A, Tables 5 and 6). This is equivalent to several major stationary sources being located within the park. On an average day with 700 snowmobiles entering the park, approximately 7 and 19 tons of HC and CO, respectively, can be emitted. On a peak day with 2,000 snowmobiles entering the park, about 20 and 54 tons of HC and CO, respectively, can be emitted (see Appendix A, Table 4). On an average July day automobiles can emit[2], by the most conservative estimate, as much as 2.5 tons of HC and 17.9 tons of CO.

[2] The maximum number of automobiles entering Yellowstone NP during any month between December 1991 and May 1999 was 285,637. An average on a July day was 9,214 automobiles. Mobile 5 emission factors are used to estimate emissions.

Table 2. Estimated Average Annual Emissions from Mobile Sources, Yellowstone National Park, in tons

Hydrocarbons (HC)						
Snowmobile Emission Factor / Automobile Emission Factor	Autos	RVs	Snowmobiles	Snowcoaches	Buses	Total
SwRI / Mobile 5	286	19	661	3	4	973
	29%	2%	68%	<1%	<1%	
SwRI / EPA FTP	58	19	661	3	4	745
	8%	3%	89%	<1%	1%	
DU / DU	93	19	780	3	4	899
	10%	2%	87%	<1%	<1%	
DU / EPA FTP	58	19	780	3	4	864
	7%	2%	90%	<1%	<1%	
Carbon Monoxide (CO)						
	Autos	RVs	Snowmobiles	Snowcoaches	Buses	Total
SwRI / Mobile 5	2089	337	1814	25	15	4281
	49%	8%	42%	1%	<1%	
SwRI / EPA FTP	483	337	1814	25	15	2675
	18%	13%	68%	1%	1%	
DU / DU	1335	337	939	25	15	2652
	52%	13%	35%	1%	1%	
DU / EPA FTP	483	337	939	25	15	1800
	27%	19%	52%	1%	1%	

Other pollutants emitted from gasoline-powered vehicles include sulfur dioxide (SO_2), ammonia, and PAHs. Limited testing performed by SwRI showed SO_2 emissions to be low (0.04 g/hp-hr) due to low sulfur content in gasoline (White and Carroll 1998). Ammonia emissions were also found to be low (0.075 g/hp-hr). Southwest Research Institute also conducted hydrocarbon speciation tests, including four compounds classified by EPA as air toxics (1,3-butadiene, benzene, formaldehyde, and acetaldehyde) and numerous PAHs (White and Carroll 1998). The results of tests on a gasoline-fueled Polaris engine showed that 1,3-butadiene, benzene, formaldehyde, and acetaldehyde were present at levels of 0.14, 0.80, 0.64, and 0.10 percent, respectively, of total HC emissions. Of the four compounds, benzene[3] had the largest emission rate at 1.26 g/hp-hr. The same study gives an emission rate for toluene of 31.78 g/hp-hr. White and Carroll also reported that in terms of total mass, 61% of PAHs were emitted in the particle phase with the remaining 39% in the vapor phase. Eighteen PAHs identified by SwRI had a combined emission rate[4] of 3643 µg/hp-hr (equivalently, for example, 58.3 mg/hr at 16 hp), with 22% (787 µg/hp-hr) of the PAHs being in the form of pyrene. This equates to 1

[3] Average of tests conducted on Polaris (1.69 g/kW-hr) and Arctic Cat (1.05 g/kW-hr) snowmobiles, as reported in Table 12, White and Carroll 1998.
[4] Sum of Total PAHs appearing in Table 14, White and Carroll 1998, converted to g/hp-hr (1 g/kW-hr = 0.7457 g/hp-hr).

pound of PAHs, 355 pounds of benzene and 8,960 pounds of toluene being emitted on a peak day (2,000 snowmobiles) at Yellowstone. Aromatic hydrocarbons, including PAHs, are considered to be the most toxic component of petroleum products, and are also associated with chronic and carcinogenic effects (Irwin *et al.* 1998).

Emission factors and calculations used for this section are found in Appendix A.

Air Quality and Personal Exposure Standards

Maximum allowable limits, or standards, for various air contaminants have been established by the EPA, and subsequently by states, for concentrations in the ambient air. Ambient air is defined as "that portion of the atmosphere, external to buildings, to which the general public has access" (Code of Federal Regulations, Part 50, 1994). EPA has established national ambient air quality standards (NAAQS) for six pollutants: CO, SO_2, nitrogen dioxide (NO_2), ozone, particulate matter less than 10 microns in size (PM_{10}), and lead. (Note that EPA recently promulgated a standard for PM less than 2.5 microns in size ($PM_{2.5}$), but the standard has been challenged and its implementation is being delayed). The NAAQS are set to protect the general public from the harmful effects of air pollutants within an adequate margin of safety. These standards apply only in those areas where the general public has access and do not apply in the workplace. Compliance with these standards is determined through the use of EPA-designated reference or equivalent analytical methods at appropriate sampling locations representative of human exposure. Non-compliance with the NAAQS requires states to take appropriate measures to reduce air pollution emissions sufficient to attain and maintain the NAAQS. Table 3 lists the NAAQS for the various pollutants, as well as the Prevention of Significant Deterioration (PSD) Class I and Class II increments. The relevance of the PSD increments will be discussed in a later section.

In addition to EPA's ambient standards, the Occupational Safety and Health Administration (OSHA) has established Permissible Exposure Limits (PELs) for numerous air contaminants to protect workers in the workplace. PELs are usually time-weighted average concentrations that must not be exceeded during any 8-hour workshift of a 40-hour workweek. A short-term exposure limit (STEL), or ceiling value, is usually measured over a 15-minute period and reflects the exposure limit that should not be exceeded at any time during a workday. National Institute for Occupational Safety and Health (NIOSH) also has published Recommended Exposure Levels (RELs) for time-weighted average exposures as well as short-term (15-minute) ceiling concentrations not to be exceeded.

Occupational exposure standards for various pollutants present in snowmobile exhaust are given in Table 4.

Table 3. National Ambient Air Quality Standards and PSD Increments, micrograms per cubic meter (parts per million)

Pollutant	*Averaging time*	*NAAQS*	*PSD Increments (Class I/Class II)*
Carbon Monoxide (CO)	1 hour[1]	40,000 (35)	None
	8 hour[1]	10,000 (9)	None
Particulate Matter, less than 10 microns (PM_{10})	24 hour[1]	150	8/30
	Annual Average	50	4/17
Particulate Matter, less than 2.5 microns ($PM_{2.5}$)	24 hour[1]	65	None
	Annual Average	15	None
Ozone (O_3)	1 hour[2]	235 (0.12)	None
	8 hour[3]	157 (0.08)	None
Sulfur Dioxide (SO_2)	3 hour[1, 4]	1,300 (0.50)	25/512
	24 hour[1]	365 (0.14)	5/91
	Annual Average	80 (0.03)	2/20
Nitrogen Dioxide (NO_2)	Annual Average	100 (0.05)	2.5/25
Lead (Pb)	Quarterly Average	1.5	None

[1] Not to be exceed more than once per year
[2] Standard attained when 3–year avg. number of expected exceedances is less than or equal to 1
[3] Standard attained when 3-year avg. of 4th highest daily maximum 8-hr concentration is less than 0.08 ppm. This standard is being challenged and its implementation is being delayed.
[4] Secondary standard set to protect public welfare effects

Table 4. Occupational Standards for Several Air Pollutants Present in Vehicle Exhaust

Pollutant	*Occupational Standards* OSHA PEL	NIOSH REL
Acetaldehyde	180 mg/m^3 (100 ppm)	270 mg/m^3 (150 ppm)
Benzene	3.26 mg/m^3 (1 ppm)	none
1,3-Butadiene	2,200 mg/m^3 (1000 ppm)	none
Benzo(a)pyrene	none	0.1 mg/m^3 (0.01 ppm)
Ethylbenzene	435 mg/m^3 (100 ppm) 545 mg/m^3 (125 ppm)(STEL)	same
Toluene	375 mg/m^3 (100 ppm) 563 mg/m^3 (150 ppm) (STEL)	same
Carbon monoxide	55 mg/m^3 (50 ppm)	40 mg/m^3(35 ppm)

OSHA PELs and NIOSH RELs are Time-Weighted 8-hour Averages; Short-Term Exposure Limits (STEL) are 15-minute averages

Studies conducted at Yellowstone NP, as discussed previously and to be discussed in the following sections, indicate that standards may have been exceeded at Yellowstone NP, particularly on those days with peak snowmobile traffic. If this is the case, then regulatory or NPS management action will be required to mitigate or eliminate these impacts.

Potential Effects on Air Quality

Ambient and Personal Exposure Monitoring

Air quality studies at Yellowstone NP have shown that the accumulation of a large number of snowmobiles in a small area, such as entrance stations and parking lots, can result in short-term exposures to very high levels of CO, PM, and HC (including toxic organics) (Air Resource Specialists, Inc. 1996, Kado *et al.* 1999). There is a direct relationship between the number of snowmobiles and emissions and, consequently, air quality levels. Meteorology also plays an important role in that cold, stable atmospheric conditions with low wind speeds hinder the dispersion of air pollutants and allow pollutants to accumulate in the immediate area of their release.

Prior to the establishment of an express lane in late 1995 at Yellowstone's West Entrance station, all snowmobiles entering the park were required to stop at one of the entrance station kiosks to pay entrance fees and receive information about the park. This resulted in long lines of snowmobiles and the accumulation of snowmobile emissions over a relatively small area leading to high levels of CO near the kiosks, particularly on days with poor dispersion conditions.

Grab sampling conducted at Yellowstone's West Entrance station by the NPS during the winter of 1995 showed that ambient CO levels could exceed 1-hour and 8-hour NAAQS for CO (35 ppm and 9 ppm, respectively) in an area immediately adjacent to entrance station booths. Maximum CO concentrations of 55 ppm and 15.9 ppm (1-hour and 8-hour averages, respectively) were measured in the vicinity of the entrance station. High concentrations of CO were highly localized and decreased rapidly with increasing distance from the source of emissions. Monitoring results indicated that CO levels decreased by a factor of 10 within 25 meters of the source of emissions. The results also showed that an hourly traffic count of 450 snowmobiles would likely result in concentrations above the 1-hour NAAQS (35 ppm CO) within about 3 meters of the entrance station kiosks. Recent monitoring conducted by the State of Montana using EPA-approved protocols at Yellowstone's West Entrance Station (Ugorowski 1999) showed a maximum 8-hour CO concentration of 8.9 ppm, which almost equaled the national 8-hour standard of 9 ppm. During the same sampling period, a 1-hour concentration of 18.2 ppm was recorded. By comparison, the State of Montana 1-hour standard for CO is 23 ppm not to be exceeded more than once per year. The State of Montana Department of Environmental Quality performed a preliminary air dispersion modeling analysis to simulate various scenarios discussed in Yellowstone's Winter Use Draft Environmental Impact Statement. The results showed that the No Action alternative (*i.e.*, current snowmobile usage), as well as a derivative of this alternative that substituted oxygenated fuels and low emissions lube oil, could result in exceedances of the 1-hour CO NAAQS (Cain and Coefield 1999).

Hourly levels of PM are likely to be correlated with hourly CO levels, as the source of emissions is the same. The majority of PM emissions from snowmobiles have been found to be of a size that are easily respirable and able to be delivered into the lung, typically in the ultra-fine range less than 100 nanometers (Carroll and White 1999). In addition, there are a number of toxic compounds that adhere to the emitted PM. PM_{10} sampling conducted by the University of California at Davis in 1999 showed an apparent gradient in concentration from the town of West Yellowstone, Montana to Old Faithful, with peak PM levels occurring at the West Entrance station. PM_{10} concentrations (nominally 8 hours in duration) were higher at Old Faithful than in downtown West Yellowstone and in a residential site in West Yellowstone for one day of sampling (February 20, 1999) (Kado *et al.* 1999).

A study conducted at Grand Teton NP (Snook and Davis 1997) showed that CO levels when trailing a single snowmobile ranged from 0.51-23.1 ppm at distances of 25-125 feet at speeds of 10-40 mph. This report also cites that the average snowmobile group size is 8, thus riders trailing a large number of snowmobiles are likely to experience significantly higher CO exposures.

High levels of air pollutants are not limited to outdoor exposures. An improperly ventilated entrance station kiosk at Yellowstone's West Entrance resulted in CO levels approaching the level of the 8-hour NAAQS for CO (9 ppm), although the levels measured were well within the OSHA's 8-hour time-weighted average of 50 ppm. Retrofitting the air intake system at the kiosk significantly reduced employee exposure. Thus, properly ventilated entrance station booths are an important consideration in protecting employee health.

Additional monitoring at Yellowstone NP has included both fixed-site and personal exposure monitoring for PM and volatile organic compounds (VOCs) (Kado *et al.* 1999). The maximum time-weighted concentration of $PM_{2.5}$ at the West Entrance on a busy President's day weekend (*i.e.*, February 13 and February 14, 1999) was 78 $\mu g/m^3$ based on 4-hour morning and afternoon samples. Morning 4-hour concentrations for February 13 and 14 were 116 and 112 $\mu g/m^3$, respectively. The morning concentration (nominally 8:30 a.m. to 12:30 p.m.) represented approximately 80% of the exposure and coincides with the time that approximately 90% of the snowmobiles entered the park on those days (Kado *et al.* 1999). The 24-hour $PM_{2.5}$ NAAQS is 65 $\mu g/m^3$, however, because of the difference in averaging times, concentrations measured at Yellowstone NP during the Kado *et al.* study are not directly comparable to the standard. The time-weighted exposure throughout the entire workshift was at or near 60 $\mu g/m^3$ at the West Entrance station (Kado *et al.* 1999). This study also showed that concentrations measured at Madison and Old Faithful were lower than those at the west entrance station likely due to these areas being more open and because snowmobilers turn off their snowmobiles on arrival at these areas.

Personal exposure measurements of PM less than 4.0 microns in size ($PM_{4.0}$), called PerPM, were conducted on park employees in a variety of job categories. Results indicated exposure varied by job category, with a snowmobile mechanic having the greatest PerPM exposure, followed by employees who worked the West Entrance station, and then snowmobile patrol rangers. West Entrance station employees who worked in the express lane (with more snowmobiles) had double the PM exposure of those who worked in the regular lanes. PerPM concentrations were measured at levels up to 160 $\mu g/m^3$ (Kado *et al.* 1999). Again, these concentrations cannot be compared directly to the NAAQS, because of differences in particle size and averaging time. However, all PM collected was thought to be less than $PM_{2.5}$.

Personal exposure measurements to VOCs were conducted for Yellowstone NP employees during the winter of 1999 University of California at Davis study. A number of toxic compounds including benzene, toluene, and formaldehyde were monitored (Kado *et al.* 1999). Of the VOCs measured, toluene had the highest relative concentration. The fixed-site VOC monitoring showed the same types of gasoline-associated toxic compounds (*e.g.*, benzene and toluene) at each location, but concentrations were highest at the West Entrance. West Entrance station employees had the greatest VOC exposure, followed by snowmobile patrol rangers, followed by a snowmobile mechanic. The study showed that the concentration of benzene for some employees could approach the RELs as established by NIOSH. The study supported "the hypothesis that Park employees and the surrounding environment are exposed to high levels of many toxic pollutants as a result of snowmobile use within the Park…" (Kado *et al.* 1999).

These monitoring results indicate levels of individual pollutants, including carcinogens such as benzene, that result from snowmobile exhaust can be high enough to be a threat to human health. Moreover, it is unknown what synergistic effects may arise from the cumulative, simultaneous exposure to various air pollutants. Therefore, it is important that employee exposure to exhaust gases be minimized. It would seem that visitors would likewise want to minimize their exposure to what are likely unhealthy levels of air pollution.

Health Effects Associated with Vehicle Emissions

Vehicle exhaust, including that from snowmobiles, contains numerous toxic compounds. The effects of these compounds are well documented and are discussed briefly in this section.

Carbon monoxide interferes with the oxygen carrying capacity of blood, resulting in lack of oxygen to the body's organs and tissues. The health threat from lower levels of CO is most serious for those who suffer from cardiovascular disease, such as angina pectoris. At much higher levels of exposure, CO can be poisonous, and healthy individuals can be affected. Visual impairment, reduced work capacity, reduced manual dexterity, poor learning ability, and difficulty in performing complex tasks are also associated with exposure to elevated CO levels (U.S. EPA 1997) as are nausea, headaches, dizziness, and death (Radtke 1997).

Particulate matter includes fine ($PM_{2.5}$) and coarse (PM_{10}) particles. Both coarse and fine particles can accumulate in the respiratory system and are associated with numerous health effects. Exposure to coarse particles is primarily associated with the aggravation of respiratory conditions such as asthma. Fine particles are most closely associated with such health effects as decreased lung function, increased respiratory symptoms and disease, and premature death. Sensitive groups include the elderly, individuals with cardiopulmonary disease, and/or asthma, and children (U.S. EPA 1997).

The effects of most concern associated with short-term exposures (less than 3 hours) to NO_2 at ambient levels seen in the U.S. include changes in airway responsiveness and pulmonary function in individuals with pre-existing respiratory illnesses and increases in respiratory illnesses in children (5-12 years old) (U.S. EPA 1997).

Exposure to air toxics contained in automobile and snowmobile exhaust can result in numerous respiratory and neurological effects. In addition, several of these air toxics have been shown to be carcinogenic. Acute exposure to acetaldehyde results in irritation of the eyes, skin, and respiratory tract in humans. Erythema, coughing, pulmonary edema, and necrosis may also occur and, at extremely high concentrations, respiratory paralysis and death are possible. EPA classifies acetaldehyde as a probable human carcinogen of low carcinogenic hazard.

Acute exposure to 1,3-butadiene results in irritation of the eyes and nasal passages, and causes neurological effects such as blurred vision, fatigue, headache, and vertigo. There is also a possible association between 1,3-butadiene and cardiovascular diseases. EPA has classified this compound as a probable human carcinogen of medium carcinogenic hazard.

Acute (short-term) inhalation exposure to benzene may cause drowsiness, dizziness, headaches, and unconsciousness in humans. These symptoms stop when exposure ceases. Exposure to benzene liquid and vapor may irritate the skin, eyes, and upper respiratory tract. Increased incidences of leukemia have been observed in humans occupationally exposed to benzene. The EPA and the International Agency for Research on Cancer (IARC) have classified benzene as a human carcinogen based on sufficient evidence from epidemiological studies (U.S. EPA 1994a; IARC 1987).

Acute exposure to ethylbenzene in humans results in respiratory effects, such as throat irritation and chest constriction, irritation of the eyes, and neurological effects such as dizziness. Ethylbenzene is not classifiable as a human carcinogen due to the limited amount of information available.

No information is available on the acute effects of Polycyclic Organic Matter, including PAHs, in humans. Chronic exposure to benzo(a)pyrene in humans has resulted in dermatitis, photosensitization in sunlight, irritation of the eyes, and cataracts. Cancer is the major concern from exposure. Epidemiological studies have reported increased lung cancer in humans exposed to emissions containing PAHs. EPA has classified benzo(a)pyrene as a probable human carcinogen of medium carcinogenic hazard (U.S. EPA 1994b). The toxicological effects of many PAHs can also be found in the NPS Environmental Contaminants Encyclopedia (Irwin *et al.* 1998).

Toluene is an air toxic that can cause irritation of the eyes and upper respiratory tract, dizziness, headaches, anesthesia, and respiratory arrest. Acute and chronic exposures can affect the central nervous system (CNS) producing CNS depression and loss of memory (Irwin *et al.* 1998).

Volatile organic compounds and NO_x, in the presence of sunlight, combine to form ozone. However, since snowmobile emissions occur during winter when photochemical production and ambient concentrations are at their minimum, the ozone-forming potential of these emissions is likely to be minimal, as are the health effects associated with exposure to ozone.

The Federal Clean Air Act Amendments of 1990 provided the option of using oxygenated fuels during the winter months in approximately 40 areas throughout the U.S. that were not meeting the NAAQS for CO. Methyl tertiary butyl ether (MTBE) and ethanol are two of several fuel additives used in oxygenated and reformulated gasoline to reduce CO emissions. Ethanol is used year-round in all gasoline-powered NPS vehicles, including snowmobiles, at Yellowstone NP and it is sold at West Yellowstone gas stations in the winter. Some small amounts of MTBE have been found in a few snowpack samples collected at Yellowstone NP immediately adjacent to roadways. This is thought to be the result of snowmobiles that have been transported with gasoline from locations that use MTBE. The extent to which either ethanol or MTBE additives are used in snowmobiles entering other NPS units is unknown, as is the occurrence of impacts associated with these additives.

MTBE in the air can cause headaches, dizziness, and eye irritation. A report prepared for the Legislature and Governor of California (Keller *et al.* 1998) states that 10% ethanol by volume in conventional gasoline can decrease emissions of CO (13% reduction), VOC (16% reduction), and benzene (11% reduction). However, it can also increase exhaust emissions of NO_x and acetaldehyde by 5% and 159%, respectively. Ethanol is known to have developmental and neurotoxic effects, although the risk of exposure to ambient levels is not clear (Keller *et al.* 1998).

Based on the types of air pollutants associated with snowmobile exhaust, as well as the quantities in which they are emitted, the cumulative health effects of what could be a highly concentrated, multi-pollutant mixture in the vicinity of snowmobiles are likely to be high. This is particularly relevant to individuals who spend a significant amount of time in the vicinity of snowmobile exhaust, such as areas of traffic congestion (entrance stations, parking lots) and poor emission dispersion.

Welfare Effects Associated with Snowmobile Emissions

In addition to health effects there are several public welfare concerns associated with snowmobile emissions. Research conducted in 1996 at Yellowstone NP by the U.S. Geological Survey showed that concentrations of ammonium and sulfate in snow positively correlated with snowmachine (*i.e.*, snowmobile, multi-passenger snow coach, and other mechanized over-snow vehicle) use, as levels of these pollutants generally declined a short distance from snowpacked roads (Ingersoll *et al.* 1997). Subsequent ammonium and sulfate sampling by the U.S. Geological Survey in 1998 was consistent with the 1996 data. In addition, in 1998, the snowpack was sampled for the presence of a number of organics. Data showed concentrations of organics, such as benzene, correlated well with snowmachine use (Ingersoll 1999). Of primary concern is the accumulation of HC and toxic organics in the snowpack. These pollutants may be flushed into nearby streams and water bodies during the spring snowmelt. The fate of these pollutants in the snowpack is currently under investigation in a study funded by the Yellowstone Park Foundation. Potential water quality concerns from snowmobile use in parks have also been addressed in a separate report (Hagemann and VanMouwerik 1999).

Releasing air pollutants near the ground under stable meteorological conditions with light wind speeds can also result in hazes accumulating along trails--potentially impairing visibility and degrading park scenic vistas. Section 169A of the Clean Air Act established as a national goal "the prevention of any future, and the remedying of any existing, impairment in mandatory class I Federal areas which impairment results from manmade air pollution." Visible emissions from motor vehicles, including snowmobiles, may interfere with the attainment of this goal and adversely affect the visitor's park experience. The use of gasohol has reportedly reduced the haze associated with snowmobile use in congested areas (White and Carroll 1998).

Status of Efforts to Reduce Snowmobile Emissions

Proposed Regulations

The EPA recently accepted comment on a Notice of Proposed Finding related to *Control of Emissions from New Nonroad Spark-Ignition Engines Rated above 19 Kilowatts and New Land-Based Recreational Spark-Ignition Engines* (U.S. EPA 1999a). The proposal addresses two issues: (1) that nonroad spark-ignition engines rated above 19 kilowatts (25 horsepower), as well as all land-based recreational nonroad spark-ignition engines, cause or contribute to air quality nonattainment in more than one ozone or CO nonattainment area; and (2) that PM emissions from these engines cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare. The EPA modeled contributions to emissions from mobile sources and determined that recreational spark-ignition engines, which includes snowmobiles, contribute 15 percent, 0.2 percent, 9 percent, and 2 percent of VOC, NO_x, CO and PM emissions, respectively (U.S. EPA 1999b). These engines are not currently subject to federal emission standards; this action begins the process leading to potential promulgation of such standards. The NPS Air Resources Division's comments on the Notice of Proposed Finding urged EPA to develop emission standards for snowmobiles and similar engines and to base the standards on the use of stringent emission control technology (National Park Service 1999). Unfortunately, even if standards were adopted, these standards would likely not take effect for a substantial number of years. For example, recent EPA emission standards applicable to marine engines (including personal watercraft whose 2-stroke engines are very similar to those used in snowmobiles) will reduce emissions by 75% by the year 2025. In California, emissions reductions will occur more rapidly with a 75% reduction scheduled by 2001 and 90% reduction by 2008. These reductions will likely be achieved mostly through the use of direct-injection 2-stroke engines rather than through the use of 4-stroke engines. Requiring snowmobile manufacturers to use direct-injection

2-stroke or 4-stroke engines would significantly reduce emissions from snowmobiles for most pollutants. However, there are no current regulations requiring their use nor has NPS encouraged or required their use systemwide to minimize potential air quality effects.

Two-stroke versus Four-stroke Engines

The California Air Resources Board reports that a personal watercraft with a 2-stroke engine, which is similar to ones used in snowmobiles, operated for seven hours produces more smog-forming emissions than a 1998 passenger car driven 100,000 miles (California Air Resources Board 1999). As previously stated, four-stroke engines emit substantially lower amounts of HC and PM than 2-stroke engines. Direct-injection 2-stroke engines are estimated to reduce HC emissions by 70% to 75% when compared to conventional 2-stroke engines (White 1999). The use of catalysts could further reduce emissions from 2-stroke engines. From an emissions standpoint, 4-strokes engines are preferred over 2-stroke engines. For example, HC emission factors for a 4-stroke engine can be a factor of 40 lower than for a 2-stroke engine whereas CO emissions are about the same. On the other hand, NO_x emissions from a 4-stroke engine can be, by some estimates, as much as 10 times greater than those from a 2-stroke engine (see Table 1 above). However, NO_x emissions can be as much as two orders of magnitude lower than HC and CO emissions. Although emission reductions between a direct-injection 2-stroke engine and a 4-stroke engine may not be as dramatic as between a 4-stroke engine and a conventional 2-stroke engine, they can nevertheless be substantial. Thus, requiring the use of cleaner engine technologies, including hybrid electric or battery electric snowmobiles, within NPS units is a sensible way of reducing emissions and, hence, the air quality impacts from snowmobiles. As stated previously, there is no impetus requiring the adoption of newer, cleaner technologies, although according to the Montana Department of Environmental Quality, three organizations have built electric snowmobiles (Montana Department of Environmental Quality 1999c).

Oxygenated Fuels

Areas that do not meet the NAAQS often use oxygenated fuels as a way of reducing CO emissions. Common fuel additives include MTBE and ethanol. The Montana Department of Environmental Quality reports that measured ambient levels of CO in Missoula have been reduced by 24.3 percent on average since the introduction of oxygenated fuels (8% ethanol) (Montana Department of Environmental Quality 1999a). Tests performed by SwRI (refer to Table 1 above) indicate substantial reductions in emissions of total HC (16%), CO (9%) and PM (24%) over conventional gasoline. Montana also reports that emissions of NO_x and two known carcinogens (formaldehyde and acetaldehyde) increase with the use of gasohol (10% ethanol).

Yellowstone NP has converted its entire unleaded gasoline-fueled winter fleet (including 106 snowmobiles) to gasohol since June 1998 in efforts to minimize emissions. According to park officials, several gas stations in West Yellowstone began offering ethanol-blended fuel and biodegradable or low-smoke oils in the winter of 1998-1999 (Yellowstone National Park 1999). Use of low-smoke lubricants can substantially reduce PM emissions as well (Montana Department of Environmental Quality 1999b).

As mentioned previously, the winter 1999 study by the DU evaluated the effects of oxygenated fuels (estimated at 8% ethanol) on snowmobile emissions using real-time remote sensing (Morris *et al.* 1999). Oxygenated fuels were found to emit 7 ± 4% less CO than engines using non-oxygenated fuels, with no apparent difference in the amount of HC emitted.

Management Considerations and Options

In making decisions regarding snowmobile use in an NPS unit, managers must take into consideration varying amounts of information regarding the potential effects that such use might have on park natural resources and the health of its visitors and employees. With respect to air quality impacts, the following aspects should be considered.

NPS Management Policies

NPS air resource management policies seek to perpetuate the best possible air quality in parks because of its critical importance to visitor enjoyment, human health, scenic vistas, and the preservation of natural systems and cultural resources (National Park Service 1988). These policies require managers to assume an aggressive role in promoting and pursuing measures to safeguard air quality related values from the adverse impacts of air pollution. Air pollution sources within parks must comply with all federal, state and local regulations. NPS Management Policies are clear that "[I]n cases of doubt as to the impacts of existing or potential air pollution on park resources, the Park Service will err on the side of protecting air quality and related values for future generations."

Existing Air Quality

NPS areas that do not meet the NAAQS or whose resources are already being adversely affected by current ambient levels require a greater degree of consideration and scrutiny by NPS managers. Areas that do not meet the NAAQS for any pollutant are designated as nonattainment areas. Section 176 of the Clean Air Act 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…[T]he assurance of conformity to such a plan shall be an affirmative responsibility of the head of such department, agency or instrumentality.

Essentially, federal agencies must ensure that any action taken does not interfere with a State's plan to attain and maintain the NAAQS in designated nonattainment areas. In making decisions regarding the use of snowmobiles within a designated nonattainment area, park managers should discuss their plans with the appropriate State air pollution control agency to determine the applicability of conformity requirements.

Notwithstanding an area's attainment designation under the Clean Air Act, NPS areas that have documented adverse effects due to air pollution must seek to mitigate or eliminate these impacts. When a new industrial or other major stationary source of pollution proposes to construct near an NPS unit where there are known adverse effects occurring, the NPS routinely requests the State permitting authority to find ways to offset proposed emissions increases that might contribute to existing adverse effects on park resources with contemporaneous emission reductions from a different source in the same area. At a minimum, NPS requests the most stringent control technologies be applied to these sources. These same policy objectives should guide management of pollution sources operating within park boundaries.

Clean Air Act Area Classifications

The Clean Air Act includes provisions to protect air quality and prevent air quality from deteriorating in areas where the air is relatively clean. One of the purposes of this "Prevention of Significant Deterioration (PSD)" program is "to preserve, protect, and enhance [emphasis added] 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.). Under the Clean Air Act, the NPS, as a federal land manager, has an affirmative responsibility to protect air quality related values, including visibility, from the adverse effects of air pollution in areas that are designated as "Class I." 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 Clean Air Act was amended. There are 48 Class I areas that are part of the National Park System (see Appendix A, Table 1 for a list of the NPS Class I areas in which snowmobile use is permitted). Congress intended that Class I areas be afforded the greatest degree of air quality protection and specified that only very small amounts of air quality deterioration be permitted. Congress also established a national goal of remedying existing man-made visibility impairment and preventing future impairment in Class I areas.

NPS areas that are not designated as Class I are Class II, and the Clean Air Act allows only moderate increases beyond baseline air quality concentrations in these areas. For Class II areas, the NPS Organic Act, the Wilderness Act of 1964, and other environmental statutes, policies, and regulations may provide a stronger basis for protection than the Clean Air Act. NPS management policies direct park managers to assume an aggressive role in protecting air quality and related values regardless of the unit's Clean Air Act designation.

Preventing Significant Air Quality Deterioration

One of the primary means for carrying out NPS responsibilities under the Clean Air Act and otherwise preventing air quality deterioration is through the review of permit applications for the construction or modification of stationary sources. Although the PSD permitting requirements of the Clean Air Act apply only to stationary sources, it is clear that the protection and enhancement of air quality in areas whose air quality is better than the NAAQS is consistent with the purposes of PSD and NPS management policies.

NPS managers must also avoid engaging in or permitting activities that cause or contribute to increases in pollutant concentrations that might exceed the maximum allowable increases for the area. The Clean Air Act and PSD regulations specify that only small increases in certain pollutants (*i.e.*, PM, SO_2, and NO_2) above a "baseline" concentration are allowed in Class I areas, while moderate increases are allowed in Class II areas. The allowable increases, called increments, are generally a fraction of the NAAQS (see Table 3 above). The baseline date for a particular pollutant is triggered when the first complete PSD permit application in an area is submitted to the permitting authority. After the baseline date is established, increases in emissions from all sources--including mobile and minor sources--must be counted to assess whether the allowable increments have been exceeded. Determining how much increment has been consumed is a modeling, as opposed to a monitoring, exercise. Once modeling indicates the increment has been totally consumed, there may be restrictions on new sources of air pollution in the area. If emissions from a new major stationary source are predicted to cause a violation of a Class I increment, the source may only be permitted if the federal land manager certifies that there will be no adverse effect on air quality related values. Otherwise, if an increment violation is discovered, states must develop additional pollution control measures to remedy the violations. The latter is true for Class II areas as well.

In parks where there has been a significant increase in snowmobile use since the late 1970s, increment consumption may be an issue. For example, PM baseline dates were established in Yellowstone NP in 1979 by both the states of Montana and Wyoming. Visitor use surveys at the park indicate the number of snowmobiles entering the park has increased substantially over the years since the baseline date was established. Increased emissions associated with increase usage must be counted as consuming the allowable increment for PM. It is possible that emissions increases from snowmobiles, as well as from other mobile sources, have consumed the entire 24-hour PM increment in the park.

Air Quality Levels and Employee and Visitor Health

There are two issues related to the potential effects of snowmobile emissions on human health. The first issue pertains to the NPS's responsibility to provide safe working conditions. Park employees in a variety of job categories can be affected by snowmobile emissions. The second issue is that NPS should also ensure that park visitors are not exposed to potentially harmful levels of air pollution. A previous section regarding the potential effects on air quality from snowmobile emissions described the potential impacts on employee and visitor health that may arise from exposure to the various constituents of snowmobile exhaust. An important consideration in decisions regarding snowmobile use, therefore, is the need to minimize employee and visitor exposure to high levels of air pollutants. This can be done by reducing either the duration or the level of exposure. Today's engine technologies (*e.g.*, 4-stroke engines) have not been used extensively in snowmobiles and there does not appear to be any real regulatory pressure to produce a much cleaner snowmobile engine for widespread use. Therefore, it appears that some of the quickest ways of reducing emissions in parks are to minimize the total number of snowmobiles entering parks or to regulate the number entering parks at any given time.

Management Options

As discussed above, emissions from 2-stroke snowmobile engines can be substantial. These emissions are highly toxic and acute exposures to high concentrations of these pollutants can affect the health of park visitors and employees. They can potentially affect visibility and other air quality related values within the park. Therefore, existing or potential air quality concerns should be factored into decisions regarding the use of snowmobiles in units of the National Park System. While the NPS continues to encourage states and the EPA to limit air pollution generated outside NPS units, the NPS should demonstrate environmental leadership by reducing emissions generated within NPS areas, by encouraging the snowmobile industry to produce cleaner engines, and by promoting the use of cleaner snowmobiles by park visitors.

Management options to reduce emissions or the impacts on ambient air quality from snowmobiles include: a complete ban on snowmobile use; the use of alternative, cleaner modes of transportation; limiting the number and/or staggering the entrance of recreational snowmobiles that are allowed in an NPS unit each day; limiting entrance to visitors with lower-emitting snowmobiles (*e.g.*, direct-injection 2-stroke or 4-stroke engines only); use of oxygenated fuels (preferably ethanol blended fuels); and/or ensuring that the accumulation of snowmobiles in small areas (*e.g.*, entrance stations) does not occur. The NPS should ensure that park fleets include newer, cleaner snowmobiles and that these fleets use oxygenated fuels and low-emissions lubricants. Finally, the NPS should also take other actions to minimize emissions from park fleets including adjusting snowmobiles for local conditions and elevations, adjusting clutches, using proper jets, keeping engines tuned, minimizing idling, and using biodegradable oils.

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Relevant World Wide Web Sites
http://www.epa.gov/oms/nonroad.htm
http://www.nature.nps.gov/toxic/index.html

Table 1. Snowmobile Use in NPS Units

NPS Unit[(1)]	State(s)	Class[(2)]	Winter 1998-1999 Use	1995-1999 Trend
Acadia NP	ME	I	Limited	None
Aniakchak NM and NPres.	AK	II	No data[(4)]	No data
Appalachian National Scenic Trail	Many	II	Limited[(3)]	None
Bering Land Bridge NPres.	AK	II	6000	Unknown
Bighorn Canyon NRA	MT, WY	II	None	None
Black Canyon of the Gunnison NP	CO	I	Limited	None
Blue Ridge Parkway	NC, VA	II	Limited	None
Cape Krusenstern NM	AK	II	6750	Unknown
Cedar Breaks NM	UT	II	No data	No data
Crater Lake NP	OR	I	No data	No data
Curecanti NRA	CO	II	Limited	None
Delaware Water Gap NRA	NJ, PA	II	Limited	None
Denali NP and NPres.	AK	I	Significant[(5)]	Increasing
Dinosaur NM	CO, UT	II	Limited	No data
Gates of the Arctic NP and NPres.	AK	II	Limited	Increasing
Glacier Bay NP and NPres.	AK	II	None	None
Grand Portage NM	MN	II	Limited	None
Grand Teton NP	WY	I	3511[(6)]	None
Herbert Hoover NHS	IA	II	Limited	None
John D. Rockefeller Jr. Memorial Parkway	WY	II	17160[(6)]	Decreasing
Katmai NP and NPres.	AK	II	Limited	Unknown
Kenai Fjords NP	AK	II	807	Increasing
Klondike Gold Rush NHP	AK	II	Limited	None
Kobuk Valley NP	AK	II	7500	Unknown
Lake Chelan NRA	WA	II	Limited	None
Lake Clark NP and NPres.	AK	II	Limited	Increasing
Mount Rainier NP	WA	I	Limited	None
Noatak NPres.	AK	II	2250	Unknown
North Cascades NP	WA	I	Limited	None
Olympic NP	WA	I	None	None
Perry's Victory and Int'l Peace Memorial	MI	II	Limited	None

Pictured Rocks NS	MI	II	26190	Slight increase
Rocky Mountain NP	CO	I	27288	Slight increase
Ross Lake NRA	WA	II	Limited	None
Saint Croix NSR	WI	II	Limited	None
Sequoia and Kings Canyon NPs	CA	I	Limited	None
Theodore Roosevelt NP	ND	I	Limited	No data
Voyageurs NP	MN	I	35410	Increasing
Wrangell-St. Elias NP and NPres.	AK	II	Limited	Unknown
Yellowstone NP	ID, MT, WY	I	63000	None
Yukon-Charley Rivers NPres.	AK	II	Limited	Increasing
Zion NP	UT	I	Limited	None

(1)These NPS areas outside of Alaska are open to recreational snowmobile operation in accordance with special regulations found at 36 CFR Part 7.
Alaska NPS units listed permit snowmobile operation by local rural residents engaged in subsistence uses under 36 CFR Part 13.

(2)Clean Air Act designation—Class I areas are allowed less air quality deterioration than Class II areas

(3)Limited use means less than 200 snowmobiles a year enter the NPS unit or use is restricted to a small area of the park, *e.g.*, access to inholdings, trails on private land cross NPS property for a short distance, use on access road leading to NPS unit, *etc.*

(4)ARD did not receive snowmobile information for the NPS unit

(5)Snowmobile numbers for Denali NP not provided

(6)Unknown if numbers for Grand Teton NP and John D. Rockefeller Jr. Memorial Parkway represent total number of snowmobiles or total number of passengers

Table 2. Baseline Snowmobile Emissions using Gasoline, in grams/hp-hr based on tests conducted by Southwest Research Institute (SwRI)

	HC	CO	NOx	PM
SWRI 98 Polaris	151	420	0.44	1.35
SWRI 98 Arctic Cat	156	363	0.50	3.45
SWRI 99 Polaris	116	376	0.69	0.70
Average	141	386	0.54	1.83

Note: The Arctic Cat test is for a liquid cooled engine, whereas the Polaris tests are for an air cooled engine. The average reflected above is a straight average, although in the Bishop et al. study only 28% of the snowmobiles entering Yellowstone at the West Entrance station were liquid cooled.

Resulting emissions per snowmobile using above average and assuming 4 hours of operation at 16 hp.

	HC	CO	NOx	PM
Emissions (g)/4h @ 16 hp	9006	24719	27	92
Emissions (lbs)/4h @ 16 hp	19.84	54.45	0.06	0.20

Table 3. Vehicle Counts, Yellowstone NP

Year	Autos	RVs	Snowmobiles	Snowcoaches	Buses	Grand Total
1992	1,100,171	96,594	59,569	1,112	4,788	1,256,333
1993	1,019,325	68,197	77,108	1,704	4,159	1,164,630
1994	1,055,122	80,004	74,181	1,564	5,317	1,209,307
1995	1,102,611	81,408	74,859	1,579	5,202	1,258,877
1996	1,051,054	65,291	64,798	1,118	6,937	1,181,142
1997	1,044,550	56,261	59,446	1,293	6,566	1,160,256
1998	1,154,234	56,830	60,110	1,326	6,741	1,271,174
1999	incomplete	64,345	62,878	1,396	6,455	Incomplete
Average	1,075,295	71,116	66,619	1,387	5,771	1,214,531

Vehicle count data obtained from NPS Public Use Statistics Office, Denver, CO

Notes: Data summed from December of previous year to November of year indicated.
Average number of autos based on 7-year average, 1992-1998; all others based on 8-year average, 1992-1999

Table 4. Emission Factors Used in Calculations

Vehicle Type, Units	HC	CO	NOx	PM	
Auto, g/mi	2.01	14.70	1.87	0.08	Note (1)
Auto, lbs per 100 miles	0.44	3.24	0.41	0.02	
Auto, g/mi	0.41	3.40	0.40	0.08	Note (2)
Auto, lbs per 100 miles	0.09	0.75	0.09	0.02	
Auto, g/mi	0.59	8.46			Note (3)
Auto, lbs per 100 miles	0.13	1.86			
RV, g/mi	2.05	35.90	3.24	0.12	Note (4)
RV, lbs per 100 miles	0.45	7.91	0.71	0.03	
Snowmobile, lbs per 4h visit	19.84	54.45	0.06	0.20	From Table 1, based on average of 5 SwRI tests
Snowmobile, g/kg	331	460			Note (5)
Snowmobile, lbs	22.27	30.95			Based on 11.2 gallons of fuel; 6 lbs per gallon
Coaches, g/mi	18.44	166.33	2.90	0.12	Note (6)
Coaches, lbs per 100 miles	4.06	36.64	0.64	0.03	
Diesel Buses, g/mi	5.57	20.21	14.63	1.20	Note (7)
Diesel Buses, lbs per 100 miles	1.23	4.45	3.22	0.26	
Snowmobiles Peak Day, tons	19.8	54.4	0.06	0.20	Based on 2,000 snowmobiles, SwRI factors
Autos, Avg Day on Peak Month	2.5	17.9	2.3	0.10	Based on 9,214 automobiles (Mobile 5 factors)
Snowmobiles Avg Day, tons	6.9	19.1	0.02	0.07	Based on 700 snowmobiles, SwRI factors
Autos, Avg Day	1.4	9.9	1.3	0.05	Based on 5,120 automobiles (Mobile 5 factors)

Notes

(1): Auto Factors obtained using Mobile 5 Emissions model assuming 2/3 auto, 1/3 LD truck mix; PM factor is certification standard

(2): Factors are US EPA certification standards, Tier 1 (EPA420-B-98-001)

(3): Factors derived from University of Denver remote sensing tests for 95-96 Denver fleet; assuming 20 mpg fuel efficiency & 6 lbs per gallon of fuel (62 g CO/kg; 4.3 g HC/kg)

(4): RV factors are from Table 4.1B.2 of Appendix H, AP-42, Volume II for Heavy-Duty Gasoline-powered vehicles at High Altitude, 1990-1997 model years, 50K miles, adjusted for avg fuel and including tampering; PM factor is certification standard for LD trucks > 5,750 lbs.

(5): University of Denver (DU) remote sensing tests (Bishop et. al.)

(6): HC,CO, and NOx factors from Tables 1.25, 1.32, 1.39, US EPA AP-42, Volume II, Appendix J for 1995 calendar year; PM factor is same as for RVs; Mobile 5 model results show the HC and CO factors to be conservative (i.e., greater than 80% to 150%, respectively).

(7): HC,CO, and NOx factors from Tables 1.25, 1.32, 1.39, US EPA AP-42, Volume II, Appendix J for 1995 calendar year; PM factor is certification standard from EPA420-F-97-014

Table 5. Total HC Emissions (TPY), Yellowstone NP

Year	Coaches	Autos	RVs	Snowmobiles	Buses	
1992	2.26	292.79	26.13	590.85	3.52	
1993	3.46	271.27	18.45	764.82	3.06	
1994	3.18	280.80	21.64	735.79	3.91	
1995	3.21	293.44	22.02	742.51	3.83	
1996	2.27	279.71	17.66	642.72	5.11	
1997	2.63	277.98	15.22	589.63	4.83	
1998	2.69	307.17	15.37	596.22	4.96	
1999	2.84	N/A	17.41	623.68	4.75	Total Emissions, tons
Average Emissions, all years	2.82	286.17	19.24	660.78	4.25	973.25

Snow Coach HC Emissions (tons) = (1,387 coaches)*(100 mi/coach)*(18.44 g/mi)/(454 g/lb)/(2000 lb/ton)= 2.82 tons

Auto HC Emissions (tons) = (1,075,295 vehicles)*(120 mi/vehicle)*(2.01 g/mi)/(454 g/lb)/(2000 lb/ton) = 286.17 tons

RV HC Emissions (tons) = (71,116 RVs)*(120 mi/RV)*(2.05 g/mi)/(454 g/lb)/(2000 lb/ton) = 19.24 tons

Snowmobile HC Emissions (tons) = (66,619 sleds)*(19.84 lb/sled)/(2000 lb/ton) = 660.78 tons(based on 4 hrs of operation @ 16 hp)

Bus HC Emissions (tons) = (5,771 vehicles)*(120 mi/vehicle)*(5.57 g/mi)/(454 g/lb)/(2000 lb/ton) = 4.25 tons

Table 6. CO Emissions (TPY), Yellowstone NP

Year	Coaches	Autos	RVs	Snowmobiles	Buses	
1992	20.37	2,137.10	458.26	1,621.71	12.79	
1993	31.21	1,980.06	323.54	2,099.19	11.11	
1994	28.65	2,049.60	379.56	2,019.51	14.20	
1995	28.92	2,141.84	386.22	2,037.97	13.89	
1996	20.48	2,041.69	309.76	1,764.07	18.53	
1997	23.69	2,029.06	266.92	1,618.36	17.54	
1998	24.29	2,242.12	269.61	1,636.44	18.00	
1999	25.57	N/A	305.27	1,711.80	17.24	Total Emissions, tons
Average Emissions, all years	25.40	2,088.78	337.39	1,813.63	15.41	4,280.62

Snow Coach CO Emissions (tons) = (1,387 coaches)*(100 mi/coach)*(166.33 g/mi)/(454 g/lb)/(2000 lb/ton) = 25.40 tons

Auto CO Emissions (tons) = (1,075,295 vehicles)*(120 mi/vehicle)*(14.70 g/mi)/(454 g/lb)/(2000 lb/ton) = 2,088.78 tons

RV CO Emissions (tons) = (71,116 RVs)*(120 mi/RV)*(35.90 g/mi)/(454 g/lb)/(2000 lb/ton) = 337.39 tons

Snowmobile CO Emissions (tons) = (66,619 sleds)*(54.45 lb/sled)/(2000 lb/ton) = 1,813.63 tons (based on 4 hrs of operation @ 16 hp)

Bus CO Emissions (tons) = (5,771 vehicles)*(120 mi/vehicle)*(20.21 g/mi)/(454 g/lb)/(2000 lb/ton) = 15.41 tons

Table 7. NOx Emissions (TPY), Yellowstone NP

Year	Coaches	Autos	RVs	Snowmobiles	Buses	
1992	0.36	272.14	41.36	1.77	9.26	
1993	0.54	252.14	29.20	2.29	8.04	
1994	0.50	261.00	34.26	2.21	10.28	
1995	0.50	272.74	34.86	2.23	10.06	
1996	0.36	259.99	27.96	1.93	13.41	
1997	0.41	258.38	24.09	1.77	12.70	
1998	0.42	285.51	24.33	1.79	13.03	
1999	0.45	N/A	27.55	1.87	12.48	Total Emissions, tons
Average Emissions, all years	0.44	265.99	30.45	1.98	11.16	309.58

Snow Coach NOx Emissions (tons) = (1,387 coaches)*(100 mi/coach)*(2.9 g/mi)/(454 g/lb)/(2000 lb/ton) = 0.44 tons
Auto NOx Emissions (tons) = (1,075,295 vehicles)*(120 mi/vehicle)*(1.87 g/mi)/(454 g/lb)/(2000 lb/ton) = 265.99 tons
RV NOx Emissions (tons) = (71,116 RVs)*(120 mi/RV)*(3.24 g/mi)/(454 g/lb)/(2000 lb/ton) = 30.45 tons
Snowmobile NOx Emissions (tons) = (66,619 sleds)*(0.06 lb/sled)/(2000 lb/ton) = 1.98 tons (based on 4 hrs of operation @ 16 hp)
Bus NOx Emissions (tons) = (5,771 vehicles)*(120 mi/vehicle)*(14.63 g/mi)/(454 g/lb)/(2000 lb/ton) = 11.16 tons

Table 8. PM Emissions (TPY), Yellowstone NP

Year	Coaches	Autos	RVs	Snowmobiles	Buses	
1992	0.01	11.63	1.53	6.02	0.76	
1993	0.02	10.78	1.08	7.79	0.66	
1994	0.02	11.16	1.27	7.49	0.84	
1995	0.02	11.66	1.29	7.56	0.82	
1996	0.01	11.11	1.04	6.54	1.10	
1997	0.01	11.04	0.89	6.00	1.04	
1998	0.01	12.20	0.90	6.07	1.07	
1999	0.01	N/A	1.02	6.35	1.02	Total Emissions, tons
Average Emissions, all years	0.01	11.37	1.13	6.73	0.92	20.14

Snow Coach PM Emissions (tons) = (1,387 coaches)*(75 mi/coach)*(0.12 g/mi)/(454 g/lb)/(2000 lb/ton) = 0.01 tons
Auto PM Emissions (tons) = (1,075,295 vehicles)*(120 mi/vehicle)*(0.08 g/mi)/(454 g/lb)/(2000 lb/ton) = 11.37 tons
RV PM Emissions (tons) = (71,116 RVs)*(120 mi/RV)*(0.12 g/mi)/(454 g/lb)/(2000 lb/ton) = 1.13 tons
Snowmobile PM Emissions (tons) = (66,619 sleds)*(0.2 lb/sled)/(2000 lb/ton) = 6.73 tons (based on 4 hrs of operation @ 16 hp)
Bus PM Emissions (tons) = (5,771 vehicles)*(120 mi/vehicle)*(1.2 g/mi)/(454 g/lb)/(2000 lb/ton) = 0.92 tons

APPENDIX B

Explanation of Changes Made to Original Report (October 1999)
on "Air Quality Concerns Related to Snowmobile Usage in National Parks"

1. **Snowmobile Use Assumptions.** In the original report the estimates for annual emissions from snowmobiles were based on the assumption of 4 hours of operation at 25 hp. These estimates were considered reasonable based on travel distances to popular destinations at the park from the different entrance stations and from discussions with Southwest Research Institute. For example, the round-trip distance to Old Faithful from the west, south, and north (Mammoth) entrance stations is 60, 80, and 106 miles, respectively. Assuming a travel speed of 25 mph, and allowing for some incidental use while in the park, 4 hours seemed reasonable. Reviewers pointed out that the total emissions being projected for each 4-hour visit based on this assumption would require the use of at least 18 gallons of fuel, based on a fuel density of 6 lbs. per gallon. This was considered to be too high by a factor of 2. It is believed that on average, between 9 and 11 gallons of fuel are used per snowmobile during a visit to Yellowstone. Although there are no statistics available indicating what the actual fuel consumption for snowmobiles is at Yellowstone, the above range of fuel consumption is considered reasonable based on total gasoline sales in the park, the number of snowmobiles entering the park, and the estimated total miles traveled based on visitor use surveys contained in Yellowstone's Winter Use DEIS. Also, a snowmobile tank has an 11-13 gallon capacity, and outfitters report that rentals are returned with 1 to 2 gallons of fuel left in the tank.

2. **Total Snowmobile Emissions.** Based on 1. above, assuming 4 hours of operation at 16 hp would bring the estimate of emissions more in line with what is likely to occur. This resulted in the total amount of emissions attributable to snowmobiles on an annual basis being reduced by approximately one-third. The original report stated that snowmobiles emitted as much as 1,195 tons of HC and 3,270 tons of CO annually. The revised report changes these estimates to 765 tons of HC and 2,100 tons of CO.

3. **Snowmobile Emission Factors.** The emission rate used in the revised report is based on the average of five tests conducted by Southwest Research Institute using conventional gasolines rather than the average of all emission factors from all studies. This resulted in some minor changes in the snowmobile emission factors used, as follows:

Changes to Snowmobile Emission Factors, Original Report vs. Revised Report, g/hp-hr.

Pollutant	Original Report	Revised Report
HC	151	141
CO	393	385
NO_x	0.7	0.54
PM	2.7	1.83

The changes resulted in further lowering the amount of emissions attributable to snowmobiles on a per-trip and on an annual basis.

4. **Automobile Emission Factors.** In the original report, automobile emissions were based on U.S. EPA Tier-1 certification standards. Reviewers pointed out that these emissions were too

low based on actual in-use measurements, and suggested that estimates obtained using EPA's Mobile 5 mobile source model be used. This resulted in a substantial increase in the factors used for HC, CO and NO_x, as presented below. Mobile 5 does not provide an estimate of PM emissions; therefore, EPA certification standards were used instead (Note: the original report erroneously cited the Tier 0 standard rather than the Tier 1 standard for PM). For Mobile 5, the vehicle mix used was: 0.67 light-duty vehicles and 0.33 light-duty trucks.

Changes to Automobile Emission Factors, Original Report v. Revised Report, g/mi.

Pollutant	Original Report	Revised Report
HC	0.41	2.01
CO	3.40	14.70
NO_x	1.0	1.87
PM `	0.20	0.08

The result of the above changes produced changes to the emissions attributable to automobiles by as much as a factor of 5 for HC and CO.

5. **Snow Coach Emissions.** In the original report, emissions for snow coaches were based on counts obtained from NPS's Public Use Statistics Office, which combined snow coaches and diesel buses in the count. Revised numbers for snow coaches and buses obtained from Yellowstone are now used. The snow coach emission factors used in the original report were based on the results of 2 measurements made by the University of Denver as part of their real-time remote sensing study in Yellowstone for a Bombardier and Ford Econoline coaches. The revised report uses emission factors obtained from EPA (AP-42, Volume II, Appendix J) for Light-Duty Trucks as follows:

Changes to Snow Coach Emission Factors, Original Report v. Revised Report, g/mi.

Pollutant	Original Report	Revised Report
HC	1.4	18.44
CO	37.8	166.33

In spite of the large difference in emission factors used, the contribution of snow coaches to total HC and CO annual emissions remains insignificant compared to those for snowmobiles and automobiles.

6. **Diesel Bus Emissions.** The original report contained no estimates for buses (buses were included in the snow coach count as explained in 5. above). An estimate for diesel bus emissions has been made using factors from EPA (AP-42, Volume II, Appendix J) for Heavy-Duty Diesel Vehicles.

7. **Comparison of Snowmobile vs. Other Mobile Source Emissions.** In the original report, NPS compared the emissions from snowmobiles to EPA certification standards only. In the revised report, emissions have been compared using all available information cited in the report. For example, snowmobile emissions were calculated based on test results from Southwest Research Institute and the University of Denver. Automobile emissions were calculated using test results from the University of Denver (Denver fleet), EPA's Mobile 5 emissions model, and EPA's certification standards. The revised report provides the range in the comparison of emissions between snowmobiles and automobiles based on the following

six comparisons (first entry represents source of snowmobile emissions estimate; second entry the source of auto emissions estimates).

1. Southwest Research Institute (SWRI) – EPA Mobile 5
2. SwRI – EPA Certification Standards
3. SwRI – University of Denver (DU)
4. DU – DU
5. DU – EPA Mobile 5
6. DU – EPA Certification Standards

The results of these comparisons (expressed as the ratio of snowmobile emission factor to automobile emission factor) are as follows:

Comparison	HC	CO
1.	45	17
2.	220	73
3.	153	29
4.	172	17
5.	50	10
6.	247	41

As a result of the above comparisons, the statement that snowmobiles emit about 100 times more CO and 300 times more HC than automobiles has been changed. The report now reflects the range of estimates calculated as "between 10 and 70 times more CO and between 45 and 250 times more HC" based on all emission factors.

8. **Calculation of PAH Emissions.** Reviewers pointed out that incorrect units had been used to calculate emissions of polycyclic aromatic hydrocarbons (*i.e.*, grams were reported as pounds). The revised report corrects this error and recalculates the amount of emissions for 2000 snowmobiles (a peak day at Yellowstone) based on the assumption that snowmobiles are operated at 16 horsepower for 4 hours. In addition, the total emissions for benzene and toluene are given as well. The text now reads: "This equates to 1 pound of PAHs, 355 pounds of benzene and 8,960 pounds of toluene being emitted on a peak day (2,000 snowmobiles) at Yellowstone." The revised report makes the comparison on the basis of 2,000 snowmobiles (a peak day) rather than on a 1000 snowmobile basis as in the original report.

9. **Comparison of Air Quality Levels to National Ambient Air Quality Standards.** The original report misstated the 24-hour $PM_{2.5}$ national ambient air quality standard. The report has been revised to indicate that the standard is 65 ug/m^3, not 60 ug/m^3. The revised report also clarifies that concentrations measured during 4-hour periods cannot be directly compared to a 24-hour standard. Language in the original report that attempted to provide some perspective on the concentrations measured at Yellowstone NP by referencing the maximum 24-hour $PM_{2.5}$ concentrations in a Los Angeles suburb has been removed. This contextual statement was misinterpreted, resulting in inappropriate comparisons.

10. **Miscellaneous Editorial Changes.** The report has been reorganized extensively to achieve better readability. Some redundancy has been removed. It also incorporates many

suggestions provided by the numerous reviewers (both internal and external to NPS). Additional information regarding health effects associated with some of the toxic compounds present in vehicle exhaust has been added. Tables of National Ambient Air Quality Standards, PSD increments and several occupational exposure standards have been added. Information on the effects of ozone and MTBE has been abbreviated, as it is believed that these pollutants do not appear to be emitted or present in significant amounts. A table has been added to the appendix indicating those parks where snowmobiling is allowed, and where available, the number of snowmobiles (or visitors) entering these NPS units.