Yellowstone National Park

2004-05 Winter Use Plan

Air Quality Analysis
of
Snowmobile and Snowcoach Emissions

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Introduction

Air quality analyses require detailed, specific technical information in order to determine the differing effect of various activities on air pollution levels. To begin, the quantities and types of air pollutants generated are necessary. This is referred to as "emissions data" and is used to compute vehicle-specific values of pollutants at a range of vehicle operating conditions. These vehicle-specific values are called "emission factors" and can be used to calculate spatial and/or temporal vehicle emissions.

This report details the data and procedures used to generate the emission factors necessary for the analyses of various alternatives of snowmobile and snowcoach operations in Yellowstone National Park (YNP). Data were obtained from past air quality and emissions testing and studies, as well as from vehicle manufacturers. In addition, certain of the emissions factors and vehicle usage data were used in atmospheric dispersion modeling analyses to calculate the ambient levels of carbon monoxide at three sites within Yellowstone National Park.

1.0 Snowmobile and Snowcoach Emissions Information

Table 1 summarizes the snowmobile and snowcoach emissions information used in the Yellowstone National Park 2004-05 Winter Use Plan air quality assessment. This analysis considers only emissions associated with visitor use of snowmobiles and snowcoaches and does not address other snowmobile use or other modes of vehicle travel within YNP. The EA alternatives under consideration impact only snowmobile and snowcoach travel and do not affect other modes of transportation.

For the existing conditions, the air quality analysis presumes that all snowmobiles are 2-stroke engines. For each alternative, the analysis presumes that all snowmobiles are 4-stroke engines meeting the proposed Yellowstone Best Available Technology (BAT) requirements. Alternative 5 allows a mix of 80% 4-stroke BAT snowmobiles and 20% standard 2-stroke snowmobiles during the first year of implementation, but the data presented in this report for Alternative 5 presume full implementation of BAT.

BAT for snowmobiles operating in Yellowstone and Grand Teton National Parks has been established for carbon monoxide and hydrocarbon emissions. For carbon monoxide emissions, BAT is 120 grams per kilowatt hour. BAT for hydrocarbons is 15 grams per kilowatt hour.

All 2-stroke and 4-stroke engine emissions data are based on the average emissions from snowmobiles tested by the equipment manufacturer or by the Southwest

Research Instituted (SwRI). Snowcoach emissions information is based on best available data, but it is recognized that the quality of emissions information on snowcoaches is much lower than data for snowmobiles. As such, the snowcoach emissions information has some unknown uncertainty, which is discussed in the report. The uncertainty also translates into other uncertainties in the analysis of alternatives with significant snowcoach usage.

Additional background on the emissions derivation for snowmobiles and snowcoaches is provided below. A comparison of the carbon monoxide (CO) and hydrocarbon (HC) emissions for each type of engine (2-stroke, 4-stroke, and snowcoach) is shown in Figure 1.

1.1 Two-Stroke Snowmobile Emissions

Two-stroke snowmobile emissions factors were calculated based on tests performed by SwRI[1]. The SwRI document is included as Appendix A to this report. Emission testing and engine performance were measured during modal engine tests following standard Environmental Protection Agency (EPA) procedures. Performance data for four two-stroke engine tests (A11-3, A11-4, W11-1, and W11-2) were used to calculate test-specific and average emission factors. A spreadsheet developed for determining emission factors from engine performance data and pollutant measurements[2] was utilized for calculating these factors for two-stroke engines. Emission factors for carbon monoxide and hydrocarbons in grams per mile for traveling snowmobiles and in grams per hour for idling snowmobiles were calculated from engine horsepower output using the SwRI information which was provided to the National Park Service by snowmobile manufacturers.

The modal testing obtained data for five varying modes of operation. Mode 5 (a slow engine speed: 1,600 revolutions per minute, rpm) approximates conditions when an engine is idling. Mode 4 (a moderate engine speed: 4,550 rpm) is representative of a snowmobile traveling at a speed of approximately 15-20 miles per hour and Mode 2 (a higher engine speed: 5,590 rpm) represents a snowmobile speed of 35-45 miles per hour. Four different engines tested by SwRI were used to calculate average 2-stroke snowmobile emissions factors. Table 1, presented previously in this report, summarizes the results. The spreadsheet details for 2-stroke engines are provided in Table 2. Appendix A, the October 1998 SwRI report, contains complete testing data.

1.2 Four-Stroke Snowmobile Emissions

Four-stroke snowmobile emissions factors were calculated in the same manner as were emissions factors for 2-stroke engines. Similar emission testing and engine performance data were obtained by SwRI for BAT-approved snowmobile engines from three different manufacturers (Arctic Cat T660, Polaris Frontier, and SkiDoo Legend with Yellowstone BAT kit)[3,4,5]. Results from tests for Mode 5 (idle), Mode 4 (15-20 mph), and Mode 2 (35-40 mph) were used to calculate emissions factors using the procedures described for two-stroke machines. Summary results are included in Table 1. The spreadsheet details are provided in Table 3.

The modal testing obtained data for five varying modes of operation. Mode 5 (a slow engine speed: 1,000-1,500 revolutions per minute, rpm) approximates conditions when an engine is idling. Mode 4 (a moderate engine speed: 6,000 rpm) is representative of a snowmobile with a 4-stroke engine traveling at a speed of approximately 15-20 miles per hour and Mode 2 (a higher engine speed: 5,590 rpm) represents a snowmobile speed of 35-45 miles per hour. Tests of four-stroke engines from three different snowmobile manufacturers have shown the manufacturers' ability to meet BAT requirements. A comparison of composite traveling hydrocarbon and carbon monoxide emissions versus BAT is shown in Table 4.

Previously, snowmobiles have operated in Yellowstone National Park at higher speeds than 35-45 mph. However, with the use of guides and enforcement of speed limits in the park, the assumption of a maximum speed in this range is reasonable. Thus, no emissions factors for higher speeds (in excess of 35 mph), which would have been obtained using Mode 1 data, were used in these analyses.

1.3 Snowcoach Emissions

Snowcoach emissions data have generally relied on information from light duty gasoline trucks (LDGT). Operating characteristics of truck engines in normal highway use are likely to be different from similar engines functioning while powering snowcoaches. It is likely that using such data may underestimate the actual snowcoach emissions. To date, only one snowcoach has undergone thorough emissions testing[6]. The results of that test, performed by SwRI, were used in these analyses and are the data for snowcoaches shown in Table 1. This test was only an engine test, not a dynamometer test of a snowcoach. Despite this limitation, the SwRI test represents the best emissions data presently available for snowcoaches and it is more appropriate to use the emissions data from this test than it is to extrapolate data from tests of a different vehicle type.

Snowcoaches are equipped with emissions control technology to reduce the amount of air pollutants released to the atmosphere. When a snowcoach engine is put under high power demand conditions, the emissions controls may be bypassed in order to obtain the necessary power output. This situation is referred to as "open loop" operation. When a snowcoach is running under normal operations, and high power is not required, the emissions controls function to reduce pollutants. This situation is referred to as "closed loop" operation. Due to the varying terrain in Yellowstone National Park and the nature of travel over snow-covered roads, the emissions data used for snowcoaches in these analyses assume that the vehicles operate two-thirds of the time in open loop and one-third of the time in closed loop.

It should also be noted that snowcoaches generally operate at slower speeds than snowmobiles. Thus, traveling emission factors for snowcoaches are only given for a speed of 15 mph.

2.0 Snowmobile and Snowcoach Emission Totals

Total engine emissions due to operations of snowmobiles and snowcoaches for Yellowstone National Park were calculated for comparison of the six scenarios (baseline conditions plus the five alternatives being considered). Estimates of the two types of vehicles used on the YNP roadways were used along with the roadway lengths and mode of operation of the snowmobiles and snowcoaches. This allowed the total emissions to be calculated.

Snowmobile usage by scenario is presented in Table 5. Note that the usages were adjusted depending on the particular roadway with information from the report Motorized Oversnow Vehicle Access Scenarios[7]. Engine emissions factors for the four pollutants (carbon monoxide, particulate matter, hydrocarbons, and nitrogen oxides) were then applied to the vehicle usage to determine total park-wide emissions.

Table 6 summarizes the total snowmobile and snowcoach emissions for each alternative for Yellowstone National Park. Data are presented for four primary pollutants: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM-2.5). Figure 2 compares the emissions for each pollutant for the baseline conditions and the various alternatives. Data tables for each of the scenarios are provided in Table 7 through Table 12. Appendix C contains the detailed data used for calculating the total emissions.

The comparisons show that all of the alternatives produce significant reductions in emissions of CO and HC compared to the baseline. PM-2.5 emission reductions are not as dramatic. For NOx, the alternatives tend to produce an increase in emissions compared to the baseline condition. However, for combustion emission sources like snowmobile engines, adjustments to significantly reduce CO and HC emissions oftentimes come with a sacrifice in NOx levels. NOx and CO emissions tend to have an inverse relationship in most fuel combustion engines. In addition, the air quality issues associated with snowmobiles are primarily related to health effects associated with CO exposures and are not related to NOx exposure. As such, the air quality benefits of the CO and HC reductions outweigh the potential increase in NOx emissions associated with the various alternatives.

Tables 7 through 12 also show the emissions for each segment used in air quality modeling. The derivation of the individual link emissions is documented below. The emission calculations are based on the snowmobiles and snowcoach factors listed in Table 1 plus the vehicle access numbers for each scenario. The vehicle access information is listed in the document Motorized Oversnow Vehicle Access Scenarios[7], which is attached to this report as Appendix D.

2.1 West Entrance

The West Entrance is a unique situation as snowmobiles and snowcoaches approach the entrance station and stop for a short time while entrance permits are checked. Emissions are based on an average approach and departure speed of 15-20 mph and an average engine idle time of 30 seconds. The approach and exit length from the West Entrance is 1,000 feet in either direction from the entrance (2,000 feet total). Snowmobile numbers for the calculations are based on the proposed entrance limits in the winter use plan, plus 7 percent to account for persons who may exit and reenter the park using their daily permit (see: Motorized Oversnow Vehicle Access Scenarios[7]).

2.2 Roadway Segments

For each roadway segment, the emissions are calculated using the 35-45 mph emissions data for snowmobiles and the 15 mph emissions data for snowcoaches (since snowcoaches tend to travel at slower speeds) plus the segment length and the vehicle access numbers from Motorized Oversnow Vehicle Access Scenarios[7]. For travel segments internal to the park, the snowmobile numbers are a percentage of total parkwide entrance limits based on estimated traffic patterns and visitor use. For segments ending at an entrance station, the snowmobile numbers are based on the entrance limits plus a factor to account for park exit and reentry. These factors, which vary by entrance, are documented in Motorized Oversnow Vehicle Access Scenarios[7].

2.3 Old Faithful Staging Area

Old Faithful is an area that receives heavy visitor use, even during winter when access is by snowmobile and snowcoach. Air emissions at the staging area were calculated only for engine idling, which is assumed to be 5 minutes on average for each unit. Engine emission calculations for the staging area did not explicitly include ingress and egress traffic as this is included in the roadway segment emissions.

For vehicle numbers, the sum of the two travel segments to Old Faithful (Madison to Old Faithful and Old Faithful to West Thumb) were used, which assumes that all vehicles on these segments enter the Old Faithful staging area. This is a quite reasonable assumption as visiting the Old Faithful geyser basin is one of the premier reasons visitors come to YNP.

2.4 Hazardous Air Pollutant (HAP) Emissions

Emissions of hazardous air pollutants (HAPs) occur in snowmobile emissions and are associated with incomplete fuel combustion in the engine. These emissions were estimated as a fraction of the estimated HC emission based on data reported in the EPA report Regulatory Analysis – Control of Air Pollution Emission Standards for Non-Road Spark-Ignition Marine Engines[8]. In the absence of specific HAP data present in snowmobile emissions, the data from marine engines are viewed as representative. Four hazardous air pollutants have been identified in the emissions from these types of engines: benzene, 1-3 butadiene, formaldehyde, and acetaldehyde. The percentage of each compound in the total volatile organic carbon (VOC) mass is listed below:

- Benzene 1.2%
- 1-3 Butadiene 0.16%
- Formaldehyde 0.36%
- Acetaldehyde 0.08%

To determine the individual HAP emissions, the percent fraction of each pollutant was multiplied by the total VOC emissions. Table 13 summarizes the HAP emissions by pollutant for each alternative.

3.0 Air Quality Modeling

Air quality modeling, also known as atmospheric dispersion modeling, is a process of employing mathematical algorithms to approximate the transport of air pollutants once the contaminants are released into the ambient air. Modeling requires information regarding the emissions of the air pollutants (source information), meteorological data, and information as to where the ambient concentrations are to be determined (receptor data). Meteorological data for use in the modeling can be either actual data that has been measured at or near the location of interest, or assumptions can be made regarding the meteorological conditions to determine ambient pollutant concentrations under specific situations. If assumed meteorology is used for modeling, the condition is usually selected to produce the expected highest ambient concentrations. These conditions are referred to as the "worst-case" and generally are chosen with a very thermally stable atmosphere ("F" stability) and a low wind speed (1 meter per second) which minimizes the spread of pollutants and thus maximizes the ambient pollutant concentrations.

Two different models approved for use by the United States Environmental Protection Agency were used for these analyses. For the entrance stations and roadways, the CAL3QHC air quality model was used. Determination of air pollutant concentrations from emissions at the staging areas was performed with the Industrial Source Complex, Short Term model, Version 3 (ISCST3). The Draft Air Quality Modeling Protocol[9] contains details on the use of both models.

The emissions information determined as described previously was used as input to the air quality dispersion models to predict the impact of snowmobile and snowcoach emissions. Air quality modeling has been performed at various locations in the park which are expected to generate the worst-case ambient air quality impacts associated with snowmobile operations: West Entrance, West Entrance travel link to Madison, and Old Faithful staging area. The various charts in Figure 3 show the modeling results for each alternative.

3.1 West Entrance Air Quality Modeling

The air quality modeling of emissions at the West Entrance was performed using the CAL3QHC air quality model[10]. This model is designed to predict air quality concentrations in the vicinity of roadway intersections. Although the West Entrance to Yellowstone National Park is not an intersection with crossing lanes, it has snowmobiles and snowcoaches stopping and idling for short periods. The traffic flow through this location has the characteristics of a signalized intersection (slow vehicle speeds, as well as vehicle queuing, stopping, and idling), and thus, use of an intersection-type model is technically appropriate for calculating air pollutant concentrations near the entrance.

CAL3QHC was run for the Yellowstone West Entrance analysis using worst-case meteorological conditions (F stability and 1.0 m/sec wind speed). Wind directions were every 5 degrees across the entire arc (0 – 360 degrees). The results returned by CAL3QHC were the worst-case 1-hour average CO concentration. Modeled emissions were based on estimated traffic at the West Entrance for the worst-case hour under each alternative, as listed below:

- Baseline Conditions 340 snowmobiles 5 snowcoaches
- Alternative #1 0 snowmobiles 52 snowcoaches
- Alternative #2 101 snowmobiles 38 snowcoaches
- Alternative #3 183 snowmobiles 26 snowcoaches
- Alternative #4 253 snowmobiles 16 snowcoaches
- Alternative #5 348 snowmobiles 5 snowcoaches

The National Ambient Air Quality Standards (NAAQS) for carbon monoxide (CO) is 35 parts per million (ppm) for a 1-hour average and 9 ppm for an 8-hour average. The CAL3QHC result can be compared directly to the 1-hour average NAAQS, as the model simulates a 1-hour time period. For the 8-hour average, the highest worst-case 1-hour average was converted to an 8-hour average using a persistence factor of 0.4. This factor was determined based on the ratio of actual 8-hour to 1-hour CO measurements collected at the West Entrance monitoring station for the period from October 1998 through December 2001. (Carbon Monoxide Monitoring in West Yellowstone, Montana 1998-2001, Jeff Coefield, Montana Department of Environmental Quality, May 2002[11]). Using the highest measured 1-hour and 8-hour averages to determine the persistence ratios, produces the highest 8-hour averages for the modeling. The data for the calculation of the persistence factor is included in Appendix E.

While the modeling shows that all scenarios, baseline conditions and the five alternatives, produce ambient levels of CO below the NAAQS, there is significant improvement in air quality for each alternative compared to the baseline. The worst-case baseline conditions indicate a maximum 1-hour CO concentration of 18.6 parts per millions (ppm), while the 1-hour CO concentrations associated with the alternatives range from 3.4 to 11.1 ppm. These values include 3.0 ppm for the West Yellowstone area 1-hour background concentration. For the 8-hour CO concentrations, the baseline modeling indicates a worst-case value of 7.4 ppm, compared to a range of 1.4 to 4.2 ppm for the five alternatives. The 8-hour carbon monoxide background of 1.2 ppm for the West Yellowstone area is included in these concentrations. The CO modeling results for the West Entrance are presented in Table 14, with and without associated background values.

3.2 West Entrance to Madison Link Air Quality Modeling

This travel segment was selected for air modeling because traffic volumes are highest compared to other segments. This is expected to result in peak emissions and associated impacts from snowmobile and snowcoach traffic.

The CAL3QHC model utilizes the CALINE-3 algorithm for calculating air quality impacts along a roadway with flowing traffic. Thus CAL3QHC was also used for the modeling of this travel segment, by setting the queuing time to zero as there is no intersection or other normal obstacle to traffic. A traffic segment of 3.25 miles was modeled as representative of all similar segments. Since all traffic for this roadway segment comes through the West Entrance, peak hourly traffic rate was the same as described previously under the West Entrance modeling for each alternative.

The same worst-case meteorology was input to CAL3QHC as used in the West Entrance modeling (F stability and 1.0 m/sec wind velocity). The predicted worst-case 1-hour average CO concentration was adjusted to an 8-hour average concentration using the 0.4 persistence factor discussed previously.

For emissions data, CAL3QHC requires one emission factor for the link, and does not distinguish between differing types of vehicles. To accommodate this input requirement, composite emission factors for each scenario were determined. These composite emission factors were calculated by averaging the snowmobile and snowcoach emission factors for the particular scenario with the weighted vehicle type usage. These weighted averages were then input to CAL3QHC for the modeling.

The modeling results show that all scenarios, baseline conditions and the five alternatives, have ambient levels of CO below the NAAQS. However, each of the five alternatives is significant improvements in ambient air quality compared to the baseline. The maximum worst-case 1-hour carbon monoxide concentration for baseline conditions along the roadway is 12.45 ppm , including a value of 0.65 ppm for the park interior 1-hour CO background. The worst-case 1-hour CO concentrations associated with the alternatives range from 0.75 to 2.05 ppm, with the 1-hour background included. The baseline modeling indicates a worst-case value of 4.96 ppm, compared to a range of 0.26 to 0.86 ppm for the five alternatives for the 8-hour CO concentrations. The CO modeling results for the West Entrance to Madison roadway are presented in Table 15.

3.3 Old Faithful Staging Area Air Quality Modeling

The Old Faithful staging area was selected for modeling because of the concentration of emissions from snowmobiles and snowcoaches bringing visitors to the Old Faithful Geyser Basin. These emissions are primarily due to idling of engines as after visitors enter and prior to them leaving the Old Faithful staging area.

The Old Faithful staging area has different physical and traffic characteristics compared to roadway traffic segments such as the West Entrance, or the West Entrance to Madison roadway. At Old Faithful, the emissions are clustered in an area (the parking lot), so a roadway or line source model such as CAL3QHC is not appropriate. Instead, the EPA Industrial Source Complex (ISCST3)[12] model was selected, utilizing the model's area source dispersion capabilities. The Old Faithful staging area emissions were assigned to an area source with dimensions 630 by 1037 meters (2077 by 3402 feet), which is the approximate size of the snowmobile parking area at Old Faithful. The modeling is based on estimated peak hourly traffic at Old Faithful for each alternative, listed below:

- Baseline Conditions 408 snowmobiles 9 snowcoaches
- Alternative #1 0 snowmobiles 67 snowcoaches
- Alternative #2 165 snowmobiles 44 snowcoaches
- Alternative #3 279 snowmobiles 28 snowcoaches
- Alternative #4 372 snowmobiles 15 snowcoaches
- Alternative #5 491 snowmobiles 8 snowcoaches

Because ISCST3 requires actual meteorological data, a 2-month January 1, 2000 through February 28, 2000) winter data set from the West Entrance monitoring site was used for model input. Even though sequential meteorological data were used, the results were treated in a worst-case manner because of the limited meteorological data set. The ISCST3 results were evaluated to determine the worst-case 1-hour average impact (regardless of the time period this impact occurred) and the 8-hour CO concentration was determined using the persistence factor of 0.4 discussed previously. This approach assumes that the worst-case meteorology may occur concurrently with the peak emissions.

The ISCST3 modeling results indicate that for all scenarios, baseline conditions and the five alternatives, the ambient 1-hour average concentrations of CO will be below the NAAQS. The five alternatives do indicate, however, that there is potential for significant improvement in air quality compared to the baseline. The worst-case baseline conditions show a maximum 1-hour CO concentration of 22.75 parts per million (ppm), while the 1-hour CO concentrations associated with the alternatives range from 0.75 to 21.25 ppm. These values include 0.65 ppm for the park interior 1-hour carbon monoxide background concentration. For the 8-hour CO concentrations, the baseline modeling indicates a worst-case value of 9.06 ppm, which exceeds the 1-hour NAAQS for carbon monoxide of 9.0 ppm, when the park interior background value of 0.26 ppm is included. This compares to a range of 0.26 to 8.46 ppm for the five alternatives. The 8-hour carbon monoxide park interior background of 0.26 ppm is included in these concentrations. The CO modeling results for the Old Faithful staging area are presented in Table 16, with and without associated background values.

4.0 Uncertainties

The results of the Yellowstone air quality analysis presented above are based on the best available information concerning emissions and other factors affecting air quality. However, in some cases, the available data on emissions are relatively limited and there are uncertainties in the data. The major uncertainties are discussed below.

Snowcoach emissions factors: Historical data on snowcoach emissions have been based on emissions tests for wheeled vehicles. As such, these emissions data may not accurately represent snowcoach engine loads when equipped with tracks. It is likely that using such data may underestimate the actual snowcoach emissions. To date, there has only been one test of an engine operating under conditions to simulate snowcoach performance to obtain emissions data. This test was only an engine test, not a dynamometer test of a snowcoach. However, even with these known limitations and their associated uncertainties, it is more appropriate to use the emissions data from this test of simulated snowcoach operations than it is to extrapolate data from tests of a different vehicle type. Future air quality analyses would benefit greatly from further testing of snowcoach emissions, thus reducing the uncertainty of the snowcoach emissions data. In addition, the fraction of time that a snowcoach operates in closed loop (with emission controls) or open loop (bypassing emission controls) is unknown. The assumption was made that snowcoaches operate one-third of the time in closed loop and two-thirds of the time in open loop. Testing of snowcoaches in actual operation could provide specific data to reduce this uncertainty.

Condensable PM emissions: The testing methods used to determine particulate emissions from vehicles such as snowmobiles collect PM on a filter, but do not measure PM that might occur from condensable organic material in the exhaust. These emissions occur in vapor phase at the exhaust outlet of the engine due to the high exhaust temperature, which means that they pass through the filter media, but could condense into liquid or solid PM mass as the emissions cool. All condensable PM emissions likely fall into the PM-2.5 size fraction. The degree to which the PM-2.5 emissions could be understated by this effect is probably a function of the HC emissions. As such, this error probably underestimates PM-2.5 from 2-stroke snowmobile engines more so than PM-2.5 from 4-stroke engines.

Worst-case modeling assumptions: The methods applied in the air dispersion modeling analysis are intended to result in estimates of worst-case short-term CO exposures (1-hour averages). The analysis does not consider the probability that such concentrations may actually occur or their potential frequency of occurrence. For example, the modeling assumes that the worst-case meteorological dispersion conditions (typically a stable atmosphere with low wind speeds) will occur simultaneously with the peak traffic hour for snowmobiles and snowcoaches. This method provides a reasonable estimate of the upper bound on the CO concentrations associated with each alternative and provides a sound basis for comparisons of the alternatives. However, the modeled

CO concentrations may not occur in reality and the probability is that concentrations at these levels, if they occur, would be relatively infrequent.

Table 1

Yellowstone National Park
Snowmobile and Snowcoach Emissions Summary

	PM-2.5			CO			HC			NO_X		
	Idle (g/hr)	15-20 mph (g/mi)	35-45 mph (g/mi)	Idle (g/hr)	15-20 mph (g/mi)	35-45 mph (g/mi)	Idle (gm/hr)	15-20 mph (g/mi)	35-45 mph (g/mi)	Idle (g/hr)	15-20 mph (g/mi)	35-45 mph (g/mi)
2-Stroke snowmobiles	3.77	4.09	1.31	266.0	220.56	242.88	473.0	179.85	78.67	0.53	0.21	0.29
4- Stroke snowmobiles	0.49	0.80	1.07	191.47	35.11	22.89	35.28	2.82	2.32	0.80	2.87	8.12
Snowcoach	Not Avail-able	0.279		7.47	66.720		30.7	1.106		487	1.394	

Table 4

Snowmobile Drive-cycle Composite Emission Factors
Compared to
Best Available Technology (BAT)

	Hydrocarbons (gm/kW-hr)	**Carbon Monoxide (gm/kW-hr)**
Arctic Cat T660 Test 1	5.62	92.30
Arctic Cat T660 Test 2	7.55	95.40
Polaris Frontier Test 1	5.44	111.58
Polaris Frontier Test 2	5.13	90.17
Polaris Frontier Test 3	6.25	109.93
Ski-Doo Legend Test 1	4.94	100.38
Ski-Doo Legend Test 2	4.63	91.47
Ski-Doo Legend Test 3	4.37	86.95
Best Available Technology (BAT)	**15**	**120**

gm/kW-hr = grams per kilowatt hour

Table 5

Snowmobile Usage by Scenario
(unadjusted)

Scenario	Snowmobiles
Baseline	765
Alternative 1	0
Alternative 2	318
Alternative 3	518
Alternative 4	690
Alternative 5	920

Table 6
Yellowstone Winter Use Plan Air Emissions Summary
Comparison of Alternatives

Alternative	CO (lb/day)	CO (ton/season)	HC (lb/day)	HC (ton/season)	NOx (lb/day)	NOx (ton/season)	PM-2.5 (lb/day)	PM-2.5 (ton/season)
Baseline Conditions	41,430	1,864	13,514	608	52	2	226	10
Alternative #1	1,686	76	28	1	48	2	8	> 1
Alternative #2	2,740	123	192	9	645	29	86	4
Alternative #3	3,537	159	309	14	1,132	51	138	6
Alternative #4	4,090	184	386	17	1,306	59	177	8
Alternative #5	5,229	235	517	23	2,771	125	233	10

Table 7
Yellowstone Winter Use Plan Air Emissions Summary
Baseline Conditions

Travel Link	Link Distance	CO (lb/day)	HC (lb/day)	NOx (lb/day)	PM-2.5 (lb/day)
West Entrance	2,000 ft	216	180	0.4	4
West Entrance to Madison	13.5 mi	8,350	2,694	10	44
Mammoth to Norris	21 mi	730	230	1	4
Madison to Norris	14 mi	3,712	1,196	4	20
Norris to Canyon Village	12 mi	2,358	760	4	12
Canyon Village to Fishing Bridge	16 mi	2,542	820	4	14
Fishing Bridge to East Entrance	27 mi	2,134	692	2	12
Fishing Bridge to West Thumb	21 mi	2,822	908	4	16
Madison to Old Faithful	16 mi	8,390	2,704	10	46
Old Faithful to West Thumb	17 mi	3,742	1,206	4	20
West Thumb to Flagg Ranch	24 mi	6,400	2,064	8	34
Old Faithful Staging Area		34	60	1	0.5
Total		**41,430**	**13,514**	**52**	**226**

Table 8
Yellowstone Winter Use Plan Air Emissions Summary
Alternative #1

Travel Link	Link Distance	CO (lb/day)	HC (lb/day)	NOx (lb/day)	PM-2.5 (lb/day)
West Entrance	2,000 ft	10	0.2	2	0.04
West Entrance to Madison	13.5 mi	346	6	8	2
Mammoth to Norris	21 mi	48	0.8	1	0.2
Madison to Norris	14 mi	162	2	4	0.6
Norris to Canyon Village	12 mi	104	2	2	0.4
Canyon Village to Fishing Bridge	16 mi	112	2	2	0.4
Fishing Bridge to East Entrance	27 mi	40	0.6	1	0.2
Fishing Bridge to West Thumb	21 mi	122	2	2	0.6
Madison to Old Faithful	16 mi	372	6	8	1.6
Old Faithful to West Thumb	17 mi	168	2	4	0.8
West Thumb to Flagg Ranch	24 mi	202	4	4	0.8
Old Faithful Staging Area		0.1	0.6	10	0.01
Total		**1686**	**28**	**48**	**8**

Table 9
Yellowstone Winter Use Plan Air Emissions Summary
Alternative #2

Travel Link	Link Distance	CO (lb/day)	HC (lb/day)	NOx (lb/day)	PM-2.5 (lb/day)
West Entrance	2,000 ft	18	2	2	0.2
West Entrance to Madison	13.5 mi	484	28	88	12
Mammoth to Norris	21 mi	82	6	24	4
Madison to Norris	14 mi	246	16	52	6
Norris to Canyon Village	12 mi	158	10	34	4
Canyon Village to Fishing Bridge	16 mi	170	10	36	4
Fishing Bridge to East Entrance	27 mi	126	12	44	6
Fishing Bridge to West Thumb	21 mi	186	12	40	6
Madison to Old Faithful	16 mi	558	36	118	16
Old Faithful to West Thumb	17 mi	254	16	52	8
West Thumb to Flagg Ranch	24 mi	448	42	148	20
Old Faithful		10	2	7	0.03
Total		**2,740**	**192**	**645**	**86**

Table 10
Yellowstone Winter Use Plan Air Emissions Summary
Alternative #3

Travel Link	Link Distance	CO (lb/day)	HC (lb/day)	NOx (lb/day)	PM-2.5 (lb/day)
West Entrance	2,000 ft	24	2	2	0.4
West Entrance to Madison	13.5 mi	596	46	154	20
Mammoth to Norris	21 mi	152	14	48	6
Madison to Norris	14 mi	302	26	86	12
Norris to Canyon Village	12 mi	192	16	54	8
Canyon Village to Fishing Bridge	16 mi	210	18	58	8
Fishing Bridge to East Entrance	27 mi	288	30	102	14
Fishing Bridge to West Thumb	21 mi	230	20	66	8
Madison to Old Faithful	16 mi	692	58	194	26
Old Faithful to West Thumb	17 mi	308	26	86	12
West Thumb to Flagg Ranch	24 mi	526	50	178	24
Old Faithful		17	3	4	0.04
Total		**3,537**	**309**	**1132**	**138**

Table 11
Yellowstone Winter Use Plan Air Emissions Summary
Alternative #4

Travel Link	Link Distance	CO (lb/day)	HC (lb/day)	NOx (lb/day)	PM-2.5 (lb/day)
West Entrance	2,000 ft	30	2	2	1
West Entrance to Madison	13.5 mi	688	60	208	28
Mammoth to Norris	21 mi	144	14	46	6
Madison to Norris	14 mi	350	32	104	14
Norris to Canyon Village	12 mi	226	20	72	10
Canyon Village to Fishing Bridge	16 mi	240	22	78	10
Fishing Bridge to East Entrance	27 mi	230	24	82	10
Fishing Bridge to West Thumb	21 mi	266	24	86	12
Madison to Old Faithful	16 mi	796	74	256	34
Old Faithful to West Thumb	17 mi	360	34	104	16
West Thumb to Flagg Ranch	24 mi	778	76	266	36
Old Faithful		22	4	2	0.1
Total		**41,130**	**386**	**1306**	**177**

Table 12
Yellowstone Winter Use Plan Air Emissions Summary
Alternative #5

Travel Link	Link Distance	CO (lb/day)	HC (lb/day)	NOx (lb/day)	PM-2.5 (lb/day)
West Entrance	2,000 ft	38	4	4	1
West Entrance to Madison	13.5 mi	836	82	284	38
Mammoth to Norris	21 mi	102	8	30	4
Madison to Norris	14 mi	438	44	148	20
Norris to Canyon Village	12 mi	280	28	94	12
Canyon Village to Fishing Bridge	16 mi	300	30	102	14
Fishing Bridge to East Entrance	27 mi	574	58	204	26
Fishing Bridge to West Thumb	21 mi	316	32	114	14
Madison to Old Faithful	16 mi	992	96	336	44
Old Faithful to West Thumb	17 mi	442	44	150	20
West Thumb to Flagg Ranch	24 mi	882	86	1304	40
Old Faithful		29	5	1	0.1
Total		**5,229**	**517**	**1,75**	**233**

Table 13
Yellowstone Winter Use Plan HAP Emissions Summary
Comparison of Alternatives

Alternative	Benzene		1-3 Butadine		Formaldehyde		Acetaldehyde	
	(lb/day)	(ton/yr)	(lb/day)	(ton/yr)	(lb/day)	(ton/yr)	(lb/day)	(ton/yr)
Baseline Conditions	162	7.30	21.6	0.973	48.7	2.189	10.8	0.486
Alternative #1	0.3	0.02	0.04	0.002	0.10	0.004	0.02	0.001
Alternative #2	2.3	0.10	0.30	0.014	0.69	0.031	0.15	0.007
Alternative #3	3.7	0.17	0.49	0.022	1.11	0.050	0.25	0.011
Alternative #4	4.6	0.21	0.62	0.028	1.39	0.625	0.31	0.014
Alternative #5	6.2	0.28	0.83	0.037	1.86	0.084	0.41	0.019

Table 14
Yellowstone National Park -West Entrance
Maximum Carbon Monoxide Concentrations

West Entrance	1- hour Carbon Monoxide			8- hour Carbon Monoxide		
	CAL3QHC Results (ppm)	Background (ppm)	Total (ppm)	CAL3QHC Results (ppm)	Background (ppm)	Total (ppm)
Existing Conditions	15.6	3.0	18.6	6.2	1.2	7.4
Alternative 1	0.4	3.0	3.4	0.2	1.2	1.4
Alternative 2	2.8	3.0	5.8	1.1	1.2	2.3
Alternative 3	5.6	3.0	8.6	2.2	1.2	2.4
Alternative 4	7.1	3.0	10.1	2,8	1.2	4.0
Alternative 5	8.1	3.0	11.1	3.2	1.2	4.2

8-hour background = 1-hour background x 0.4 (persistence factor)
1-hour average CO standard = 35 ppm
8-hour average CO standard = 9 ppm
ppm ≡ parts per million

Table 15
Yellowstone National Park - West Entrance to Madison Roadway
Maximum Carbon Monoxide Concentrations

West Entrance To Madison Roadway	1- hour Carbon Monoxide			8- hour Carbon Monoxide		
	CAL3QHC Results (ppm)	Background (ppm)	Total (ppm)	CAL3QHC Results (ppm)	Background (ppm)	Total (ppm)
Existing Conditions	11.8	0.65	12.45	4.7	0.26	4.96
Alternative 1	0.1	0.65	0.75	0.0	0.26	0.26
Alternative 2	0.4	0.65	1.05	0.2	0.26	0.46
Alternative 3	0/7	0.65	1.35	0.3	0.26	0.56
Alternative 4	1.0	0.65	1.65	0.4	0.26	0.66
Alternative 5	1.4	0.65	2.05	0.6	0.26	0.86

8-hour background = 1-hour background x 0.4 (persistence factor)
1-hour average CO standard = 35 ppm
8-hour average CO standard = 9 ppm
ppm ≡ parts per million

Table 16
Yellowstone National Park - Old Faithful Staging Area
Maximum Carbon Monoxide Concentrations

Old Faithful Staging Area	**1- hour Carbon Monoxide** (ppm)			**8- hour Carbon Monoxide** (ppm)		
	ISCST3 Results (ppm)	Background (ppm)	Total (ppm)	ISCST3 Results (ppm)	Background (ppm)	Total (ppm)
Existing Conditions	22.1	0.65	22.75	8.8	0.26	9.06
Alternative 1	0.1	0.65	0.75	0.0	0.26	0.26
Alternative 2	6.5	0.65	7.15	2.6	0.26	2.86
Alternative 3	10.9	0.65	11.55	4.4	0.26	4.66
Alternative 4	14.5	0.65	15.15	5.8	0.26	6.06
Alternative 5	20.6	0.65	21.25	8.2	0.26	8.46

8-hour background = 1-hour background x 0.4 (persistence factor)
1-hour average CO standard = 35 ppm
8-hour average CO standard = 9 ppm
ppm ≡ parts per million

Figure 1

Yellowstone National Park
Carbon Monoxide Emissions by Vehicle Type

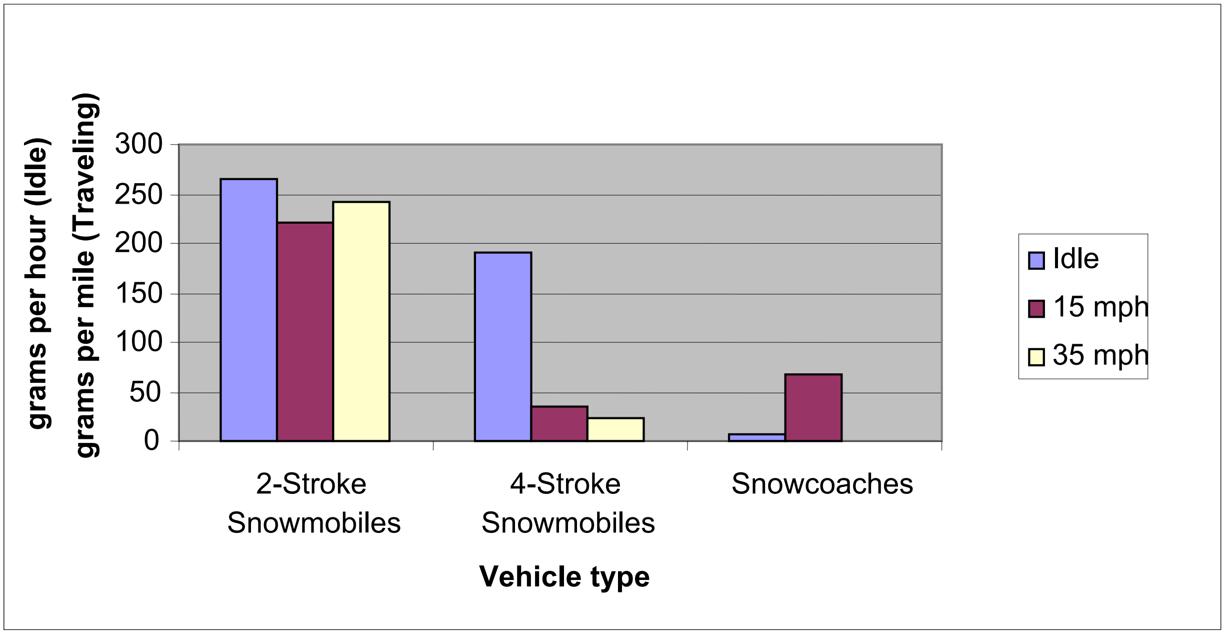

Figure 2

Yellowstone National Park
Hydrocarbon Emissions by Vehicle Type