National Park Service
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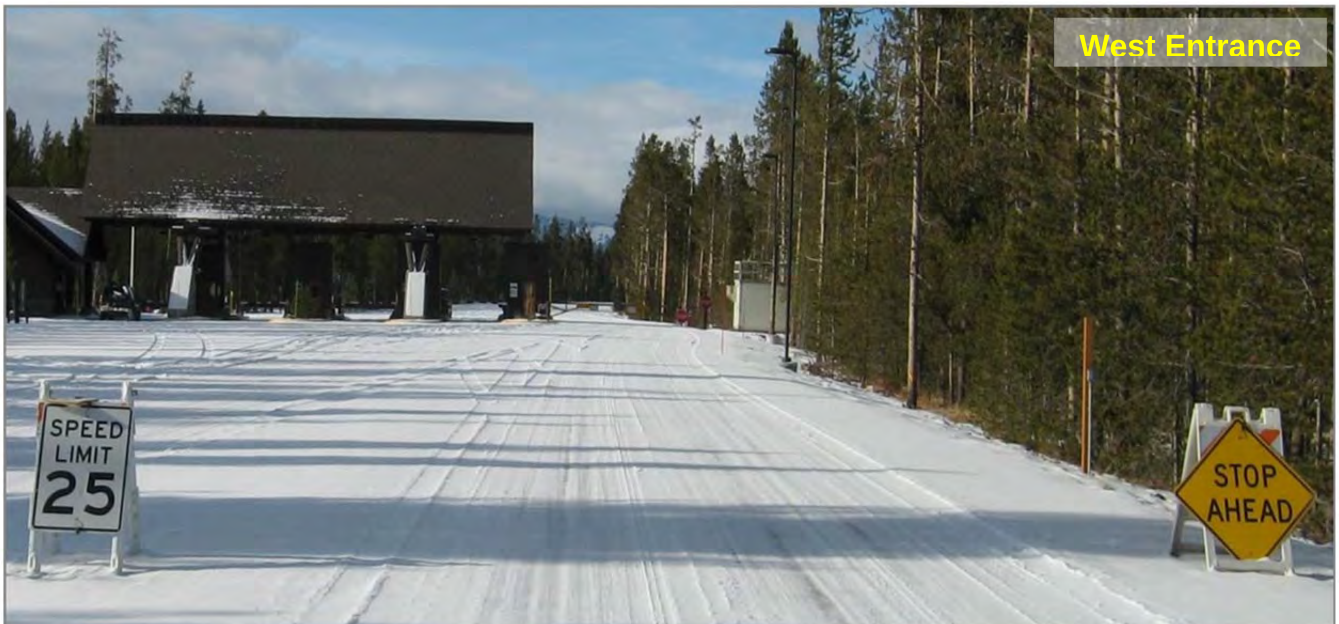
Natural Resource Stewardship and Science

Winter Air Quality in Yellowstone National Park

2009-2011

Natural Resource Technical Report NPS/NRSS/ARD/NRTR—2012/551



ON THE COVER
Views from the two winter vehicle monitoring stations in Yellowstone National Park, West Entrance and Old Faithful.
Photographs by Air Resource Specialists, Inc.

Winter Air Quality in Yellowstone National Park

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John D. Ray, Ph.D.

U.S. Department of the Interior
National Park Service
National Resource SS
Fort Collins, Colorado

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from the Air Resources Division website (http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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Executive Summary

The air quality in Yellowstone National Park was monitored at two locations within the park and at a location near the center of West Yellowstone city as part of the adaptive management program on the use of over-snow winter motor vehicles. The leading indicators used were ambient concentrations of carbon monoxide (CO) and particulate matter of 2.5 micrometers or less ($PM_{2.5}$). New measurements of nitrogen oxides (NO_x) have been added at the West Entrance station .

The monitoring data from West Entrance near the town of West Yellowstone, MT, is used to characterize for overall air quality and its relationship to traffic, because of its longer record and detailed traffic counts. Old Faithful is a destination for most of the winter use vehicles and another congestion point; CO and $PM_{2.5}$ concentrations are lower at Old Faithful than at the West Entrance. CO and $PM_{2.5}$ are also monitored outside the park in the city of West Yellowstone, MT in cooperation with the Montana Department of Environmental Quality (MT DEQ); summary data from the urbanized area are reported here for comparison.

This report updates prior air quality and emission reports. Prior reports (http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm) provide monitoring and instrument details and background information.

The notable findings for this two year period are:

- Hourly and 8-hour concentrations of CO are at low at the West Entrance and have repeated in the same range for the last 3-7 years; at Old Faithful, concentrations are slightly lower than at the West Entrance.

- Air quality at Yellowstone meets the national standards set by the Environmental Protection Agency (EPA) for CO and $PM_{2.5}$ to protect human health. The CO, however, is present above regional background concentrations (between 0.1 and 0.2 ppm) in areas near vehicle routes, especially during the winter.

- Daily average concentrations of $PM_{2.5}$ continue to decrease in the park while measurements of $PM_{2.5}$ within the city of West Yellowstone are the same or higher than previous winters. $PM_{2.5}$ concentrations in the City of West Yellowstone do not violate the national standard.

- At current vehicle emission levels from over-snow vehicle (OSV) traffic, the majority of $PM_{2.5}$ concentrations appear to be coming from non-park traffic sources at the West Entrance and at Old Faithful.

- Nitrogen dioxide (NO_2) concentrations road-side at the West Entrance are a larger percentage of the new 1-hour health standard for NO_2 than CO or $PM_{2.5}$ are for their standards. Although the NO_2 concentrations are of concern, the NO_2 is below the standard.

Acknowledgments

As with all air quality monitoring done in the parks, a large number of people contribute to the data collection and processing. A large thanks to John Faust and Jessica Ward from Air Resource Specialists for oversight of the analyzers and validation of the data. Mary Hektner, John Sacklin, and Roy Renkin at Yellowstone provided valuable direction and assistance. John Klaptosky from Yellowstone NP and the Montana Department of Environmental Quality provided the onsite operator services.

Introduction

This report is an update (Ray, 2007; Ray, 2008; Ray, 2010) that summarizes the carbon monoxide (CO) and particulate matter of 2.5 micrometers or less ($PM_{2.5}$) monitoring data from winters 2009-2011 and provides a historical perspective of monitoring data at Yellowstone National Park. The primary interest is trends in air quality that might reflect on winter use policy and the present conditions as compared to the national standards (EPA 2008) set by the Environmental Protection Agency (EPA). New in this report are the first road-side measurement of nitrogen oxides (NO_x) at Yellowstone and a winter evaluation of the radar-detector traffic counter.

Methods

$PM_{2.5}$ and CO monitoring

Details on monitoring locations and methods were given in prior reports (Ray, 2007; Ray, 2008) (http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm). Two park service monitoring stations were active during the 2009-2011 period, Old Faithful and West Entrance, plus the State-operated station in central West Yellowstone town was active. Additional data was reviewed from the CASTNet and IMPROVE station near Lake Village at the water tank location. The measurements included $PM_{2.5}$, CO, and meteorology plus NO_x measurements at the West Entrance station.

Roadside NO_x measurements

Hourly NO_x measurements were initiated at the West Entrance station because of a new hourly EPA standard for nitrogen dioxide (NO_2) allowing a daily maximum of only 100 ppb (parts per billion). Three different instruments based on the chemiluminesence of nitric oxide (NO) were used. The first instrument was an older Thermo Environmental Instruments (TEI) model 42T used during the period December 15, 2009 to February 10, 2010. A multiple-point calibration audit indicated some non-linearity and positive value error at high concentrations in the instrument span range. On February 12, 2010 a new Teledyne Advanced Pollution Instruments (TAPI) model 800eu analyzer was installed at the West Entrance station. This instrument passed audit performance checks and provided the most reliable results. The third NO_x analyzer was a lower resolution instrument from 2B Technologies (model 400 NO analyzer and model 410 NO_x converter) that was installed on January 11, 2010 and operated until the end of March. Data through Spring 2011 is from the TAPI instrument.

Figure 1. (A) View of the relocated West Entrance station at Yellowstone looking west. (B) The air monitoring shelter at the side of the road near the exit lane.

Data were collected from NO_x analyzers at 10-minute intervals and as hourly averages. Data validation for the TEI and TAPI analyzer data were provided by the Montana Department of Environmental Quality (MT DEQ) and submitted to the EPA AQS database. The 10-minute data went through a screening program and invalidated hourly values were removed. NO_2 concentrations were calculated as the difference between the NO_x and NO measurements. During the winter time measurements it was noted that a very high percentage of the total nitrogen oxides (NO_x) was NO. In the atmosphere, NO reacts fairly quickly with ambient ozone to form NO_2, hence, the reason that NO_x (the sum of NO_2 plus NO) is often considered. The TAPI NO_x analyzer was used continuously through winter of 2011 and validated hourly data processed by MT DEQ was obtained from the EPA AQS database up to March 31, 2011.

IMPROVE data

$PM_{2.5}$ data is collected at an IMPROVE station that is 1 km northeast of Lake Village near a buried water tank on a hillside above a park service area. This monitor is part of the visibility monitoring program and measures speciated fine mass on filters. Samples are taken for 24-hours every third day using an automated system with weekly filter cassette changes. Analysis for mass, chemical content, and various elements are made by lab contractors and the results reported on the VIEWS web site at http://vista.cira.colostate.edu/views/. Full information on the site, instrumentation, and access to data is available from the VIEWS website.

Traffic monitoring

Traffic counting is more difficult in the winter due to the increasing thick layer of consolidated snow that builds up on the highway surface during the winter. For the last several years, the park service gate attendants have manually recorded on an hourly basis the type of vehicle and number entering the park. Data is reported hourly and summed for the day. The number of passengers is recorded and the number of park administrative vehicles counted separately and not reported as visitors.

A radar traffic counter was installed on a pole alongside the road to the east of the entrance station during the move and reconstruction of the entrance structure. Initial tests in December 2009 showed that the field of view for the radar unit was inadequate to capture vehicle traffic in all lanes. Because device specifications called for the sensor mount to be higher and farther from the road, a special tower was mounted farther down the road from the entrance structure to get the required height and distance from the road. This resulted in the radar unit field of view being near where the multiple lanes merged to the 2-way traffic section of road. Data was collected with a computer and retrieved remotely by the field support contractor. Time resolution for the traffic counts was 10 minutes.

A third traffic measurement technique was employed to check the radar traffic unit at the 10-minute resolution. A digital camera was set up to take images when triggered by a sonic motion sensor. The field of view was across the full width of the road from the top of the monitoring shelter (Figure 1B) looking southeast. Each image was stored on a local computer and later retrieved for processing. Each image was viewed by a technician and the number and type of vehicles were counted for each 10-minute period. The camera images provide more information, for example, the configuration of snowcoaches and the concessionaire, the type of snowmobile and number of riders. Weather conditions are also evident such as cloudy, clear, or snowing. 10-minute data were compared to the radar counter and hourly vehicle sums to the gate counts. The camera count method captured the exit traffic counts for comparison to the radar counts and pollutant measurements.

At Old Faithful, a digital camera was used to get the timing and general volume of use. In the winter of 2009–2010 the temporary parking lot on the southeast was used through the whole winter season. This lot is upwind of the monitoring shelter and near the temporary warming yurts. Traffic normally enters along a road that curves just in front of the monitoring shelter. In winter of 2010–2011 the new visitor center had been completed and construction materials removed. As a result, the southeast lot was unused during December 2010 in favor of the traditional lot south of the Visitor Center. In January 2011 and for the rest of the winter, the usage of the southeast lot was low. As a consequence the air monitoring was farther from the OSV sources and the measured air quality concentrations were lower than expected. The OSV parking will have to be returned to the southeast lot or the monitoring station moved if the air quality data at Old Faithful is to be used for adaptive management.

Figure 2. Winter 2009–2010 view of the temporary southeast parking lot. Over snow vehicles enter along the road that curves around in front of the monitoring shelter. The view is looking southwest towards Snow Lodge.

Summary Statistics

The hourly data are summarized here for comparison to the National Ambient Air Quality Standards (NAAQS) set by EPA for CO and $PM_{2.5}$ and to several other statistical metrics used in prior reports as part of the park's adaptive management of Winter Use Policy. The standards given in Table 1 are for averaging periods of 1-hour, 8-hours, or 24-hours. Summary data (Tables 2, 3, & 4) related to NAAQS are normally compared to data collected over a year, however, the data summary tables here are only for the winter vehicle traffic period in Yellowstone National Park, a three-month period when snow conditions are suitable for over-snow travel**.**

A summary of the OSV traffic counts is provided in Tables 5 and 6. The OSV traffic (NPS,2011) is down for the 2008-2009 winter by 26% for the West Entrance from the previous winter. The daily average snowmobile traffic through the West Entrance is about 112 units/day and 174 units/day for all entrances. In general, holidays and weekends tend to have higher traffic counts and other periods less. West Entrance traffic for 2009–2010 was down 6% compared to winter 2008-2009 then an increased by 7.7% for winter 2010–2011.

Table 1. Ambient air quality standards (AAQS) for carbon monoxide (CO) and particulate matter less than 2.5 micrometers ($PM_{2.5}$). (ppm = parts per million; $\mu g/m^3$ = micrograms per cubic meter)

Standard	Pollutant	1-hr CO (ppm) [1]	8-hr CO (ppm) [1]
National AAQS	CO	35	9
Montana AAQS	CO	23	9
Wyoming AAQS	CO	35	9
Standard	**Pollutant**	**24-hr $PM_{2.5}$ 98th percentile ($\mu g/m^3$) [2]**	
New NAAQS [3]	$PM_{2.5}$	35	
Montana AAQS	$PM_{2.5}$	35	
Wyoming AAQS	$PM_{2.5}$	65[4]	
Standard	**Pollutant**	**1-hr NO_2 (ppb)**	
National AAQS	NO_2	100	

1. Not to be exceeded more than once per year. Link to EPA NAAQS standards: http://www.epa.gov/air/criteria.html ; WY DEQ http://deq.state.wy.us/aqd/standards.asp ; MT DEQ http://www.deq.state.mt.us/AirMonitoring/citguide/appendixb.html
2. The 3-year average of the 98th percentile of 24-hour concentrations at each monitor within an area must not exceed 35 $\mu g/m^3$. The winter 98th percentile in the associated tables is given only to demonstrate the improvement between winter seasons. Comparison with the annual standard is not shown. For consistency, the 24-hour day is used to average the hourly $PM_{2.5}$.
3. Revised $PM_{2.5}$ standard by EPA Oct. 2006, down from 65 $\mu g/m^3$
4. Wyoming has proposed a state standard of 35 ug/m^3. http://deq.state.wy.us/aqd/proposedrules.asp

For the winter 2009–2010, the CO maximum 1-hour concentrations (Table 2) tended to be slightly higher (7.6 ppm West Entrance, 2.5 ppm Old faithful) at the two park monitoring locations than in winter 2008-2009 (2.4 ppm, 1.1 ppm). Concentrations in winter 2010–2011 were lower (4.3 ppm, 1.0 ppm) than the 2009-2011 winter for CO. This pattern did not follow the OSV (over-snow vehicle) traffic trend (Table 6 or Figure 3). For CO, the lowest concentrations were at Old Faithful and higher concentrations were observed at the West

Entrance. None of the locations exceeded the CO standards. For CO, the West Yellowstone city center station concentrations were much higher than the park sites at the West Entrance and Old faithful and also did not exceed the standard for either the 1-hour or the 8-hour NAAQS standard periods.

Table 2. Statistical comparison of CO (ppm) between Yellowstone NP winter monitoring stations.

West Entrance								
Winter season → Statistic CO	Max 1-hr	% of NAAQS	Max 8-hr	% of NAAQS	Average	90th percentile	2nd max 1-hr	2nd max 8-hr
2010–2011	4.3	12%	0.9	10%	0.18	0.3	3.8	0.8
2009–2010	7.6	22%	1.7	19%	0.21	0.4	4.1	1.3
2008-2009	2.4	7%	0.6	6%	0.22	0.3	2.3	0.6
2007-2008	6.1	17%	1.6	18%	0.23	0.4	4.2	1.5
2006-2007	3.7	11%	0.8	9%	0.19	0.3	3.5	0.8
2005-2006	2.1	6%	0.9	10%	0.23	0.4	1.7	0.7
2004-2005	2.8	8%	1.0	11%	0.24	0.4	2.6	0.9
2003-2004	6.4	18%	1.3	14%	0.26	0.5	3.1	1.1
2002-2003	8.6	25%	3.3	37%	0.57	1.3	8.4	2.1
West Yellowstone City, MT								
Winter season → Statistic CO	Max 1-hr	% of NAAQS	Max 8-hr	% of NAAQS	Average	90th percentile	2nd max 1-hr	2nd max 8-hr
2010–2011	4.5	13%	1.6	5%	0.4	0.7	3.7	1.5
2009–2010	3.6	10%	1.9	5%	0.44	0.8	3.5	1.89
2008-2009	7.9	23%	3.1	9%	0.48	0.9	5.9	2.99
2007-2008	6.7	19%	2.2	25%	0.44	0.7		
2006-2007	5	14%	2.4	27%	0.48	0.9		
Old Faithful								
Winter season → Statistic CO	Max 1-hr	% of NAAQS	Max 8-hr	% of NAAQS	Average	90th percentile	2nd high 1hr CO	2nd hi 8hr CO
2010–2011	1.0	3%	0.3	3%	0.19	0.26	0.8	0.3
2009–2010	2.5	7%	0.8	9%	0.19	0.25	2.1	0.8
2008-2009	1.1	3%	0.4	4%	0.14	0.18	0.8	0.4
2007-2008	0.9	2%	0.4	5%	0.19	0.24		
2006-2007	0.9	3%	0.4	4%	0.27	0.19		
2005-2006	1.6	4%	0.5	6%	0.18	0.26		
2004-2005	1.6	4%	0.8	7%	0.12	0.29		
2003-2004	2.2	6%	0.9	10%	0.26	0.5		
2002-2003	2.9	8%	1.2	13%	0.24	0.5		

Table 3. Statistical comparison of $PM_{2.5}$ ($\mu g/m^3$) between Yellowstone NP winter monitoring stations.

West Entrance						
Winter season[1]	Max 1-hr	Max Daily (24-hr)	98th percentile[2]	% of Std	Average	2nd max daily
2010–2011	22	6	6	20%	0.7	6
2009–2010	88	7	5	15%	1.0	5
2008-2009	53	5	5	14%	1.5	5
2007-2008	44	10	8	22%	2.6	NA
2006-2007	40	9	9	25%	2.1	NA
2005-2006	44	7	6	10%	1.9	NA
2004-2005	21	6	6	9%	2.9	NA
2003-2004	29	8	7	11%	4.0	NA
2002-2003	81	15	17	26%	8.2	NA
West Yellowstone City, MT						
Winter season	Max 1-hr	Max Daily (24-hr)	98th percentile[2]	% of Std	Average	2nd max daily
2010–2011	184	33	28	80%	11.6	27
2009–2010	154	38	36	103%	12.2	36
2008-2009	145	28	27	77%	12.3	27
2007-2008	167	25	22	63%	5.6	NA
2006-2007	119	32	32	91%	12.9	NA
Old Faithful						
Winter season	Max 1-hr	Max Daily (24-hr)	98th percentile[2]	% of Std	Average	2nd max daily
2010–2011	29	4	4	23%	2.6	4
2009–2010	21	6	6	17%	3.2	5
2008-2009	23	6	5	15%	3.1	5
2007-2008	32	8	6	17%	3.2	NA
2006-2007	20	7	6	18%	3.3	NA
2005-2006	56	9	9	13%	3.5	NA
2004-2005	38	6	9	14%	4.0	NA
2003-2004	151	16	9	14%	4.9	NA
2002-2003	200	37	21	33%	6.9	NA

1. It is recognized that the $PM_{2.5}$ comparisons here are for only a 3-month winter period and not over 12-months as the $PM_{2.5}$ are normally calculated.
2. $PM_{2.5}$ percent of standard are calculated based on the Oct. 2006 revised standard for consistency.

EPA has revised the NO_2 standard from an annual average to one based on daily maximum 1-hour concentrations (EPA, 2010). For road-side measurements, the NO_2 NAAQS is now 100 ppb for a daily maximum 1-hour. In the early winter 2009–2010 there were several instrument problems that led to questions about the data. Qualitatively there were several high NO_x values during Dec. and Jan. that were larger than NO_x measured later in the winter. There is uncertainty in the NO_x concentrations measured of about 30% for the early winter period when the TEI 42 analyzer was used. Starting on Feb. 12, 2011 a new TAPI NO_x analyzer was used. Data from that date onward is what is presented in the tables and used for all the comparisons. In tables 4 & 5 are the NO_2 and NO_x concentrations observed at the West Entrance, broken out by season. A seasonal pattern is not definitive with the current dataset. Winter 2010–2011 did have some high NO_2 periods. The number of vehicles per day is quite different by season; winter traffic at the West Entrance is about 112 snowmobiles and 30 snowcoaches per day, summer is about 2,250 vehicles per day.

Table 4. NO_2 concentrations measured at the Yellowstone West Entrance roadside.

Period	Max Daily (1-hr)	98th percentile	% of NAAQS	Average	2nd max daily 1-hr
Winter 2009–2010*	18	18	18	2.1	16
Spring 2010	26	26	26	1.5	14
Summer 2010	26	22	22	2.3	23
Fall 2010	21	21	21	0.8	17
Winter 2010–2011	82	67	67	5.8	60
Spring 2011	22	22	22	0.8	15

*Covers period Feb. 12 to Mar. 15, 2010 only for winter 2009–2010

Table 5. NO_x concentrations measured at the Yellowstone West Entrance road side. ($NO_x = NO + NO_2$)

Period	Max Daily (1-hr)	98th %tile	Average	2nd max daily 1-hr	90th %tile
Winter 2009–2010	49	49	2.5	31	28
Spring 2010	76	76	2.0	26	22
Summer 2010	85	69	4.6	73	47
Fall 2010	54	54	1.2	30	16
Winter 2010–2011	140	109	6.8	95	64
Spring 2011	62	62	1.3	38	57

Table 6. OSV entering Yellowstone National Park during winter.

	Yellowstone West Entrance station			All Yellowstone gates		
End Year	Snowmobiles	Snowcoaches	Total	Snowmobile	Snowcoach	Total
1997-1998	40,869	706	41,575	60,110	1,326	61,436
1998-1999	44,213	767	44,980	62,878	1,396	64,274
1999-2000	42,620	777	43,397	62,531	1,535	64,066
2000-2001	45,689	816	46,505	67,653	1,591	69,244
2001-2002	50,888	889	51,777	69,196	1,605	70,801
2002-2003	33,458	998	34,456	47,799	1,653	49,452
2003-2004	14,765	1,181	15,946	22,423	2,058	24,481
2004-2005	8,743	1,185	9,928	15,695	1,926	17,621
2005-2006	13,104	1,371	14,475	21,916	2,463	24,379
2006-2007	14,682	1,453	16,135	24,516	2,448	26,964
2007-2008	14,135	1,582	15,717	23,814	2,653	26,467
2008-2009	10,139	1,495	11,634	15,655	2,418	18,073
2009–2010	9,394	1,544	10,938	16,454	2,525	18,979
2010–2011	10,083	1,705	11,788	16,787	2,713	19,500

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

Table 7. Seasonal variation in CO at the West Entrance for 2010.

2009–2010	Max. 1-hr CO	Max. 8-hr CO	Season average CO	90th percentile CO
Winter	4.12	1.10	0.22	0.38
Spring	0.60	0.27	0.16	0.20
Summer	6.93	1.78	0.18	0.30
Fall	0.74	0.33	0.12	0.20

The field data for the gaseous pollutants and weather sensors at the collection frequency sampled can be accessed from a web page at: http://12.45.109.6/ . IMPROVE particulate data are available at: http://views.cira.colostate.edu/web/ .

Discussion

The West Entrance (Tables 2 & 3) station continues to have higher concentrations of CO and $PM_{2.5}$ than the Old Faithful station. This is a result of higher traffic density at the entrance station, where over-snow vehicles (OSV) stop and idle for a time and then accelerate (Bishop, 2009; Ray, 2007). In addition, the air quality monitoring station at the West Entrance is close to the road as opposed to the station at Old Faithful. Dual peaks in CO occur daily that correlate with the OSV traffic activity between 8-10 am and 3-5 pm. At the Old Faithful station, CO peaks between 11 am and 2 pm when there is the most OSV activity in the parking area.

The CO at the West Entrance was lower in 2010–2011 than the previous winter, based on all the statistical metrics of measurements. Total OSV traffic through the west entrance was up slightly from the previous year (Figure 3, Table 6). The CO concentrations at the west entrance are now less than 15% of the National Ambient Air Quality Standard (NAAQS) set by the US Environmental Protection Agency. For CO, the NAAQS is 9 ppm for an 8-hour period (Table 1). For $PM_{2.5}$, the concentrations are about 20% of the NAAQS and have followed a similar trend to CO at the West Entrance (Figure 3). In most urban locations these conditions would be considered acceptable air quality. At Yellowstone NP, the CO is still higher at the West Entrance than the regional background concentrations of about 0.15 ppm (Table 7).

The overall winter traffic volume is compared to summary air quality statistics in Figures 3 and 4. CO and $PM_{2.5}$ concentrations have gone down as the OSV traffic decreased and the Yellowstone best available technology (BAT) regulation was introduced for snowmobiles starting in winter 2002-2003. Air quality conditions decreased to much lower concentrations in winter 2003-2004 and have stayed near those levels since. Figure 5 summarizes how CO and $PM_{2.5}$ have changed at the two park monitoring stations relative to the NAAQS standards. Air quality is acceptable and at the lower ranges of the NAAQS scale. There has been relatively little change since 2004.

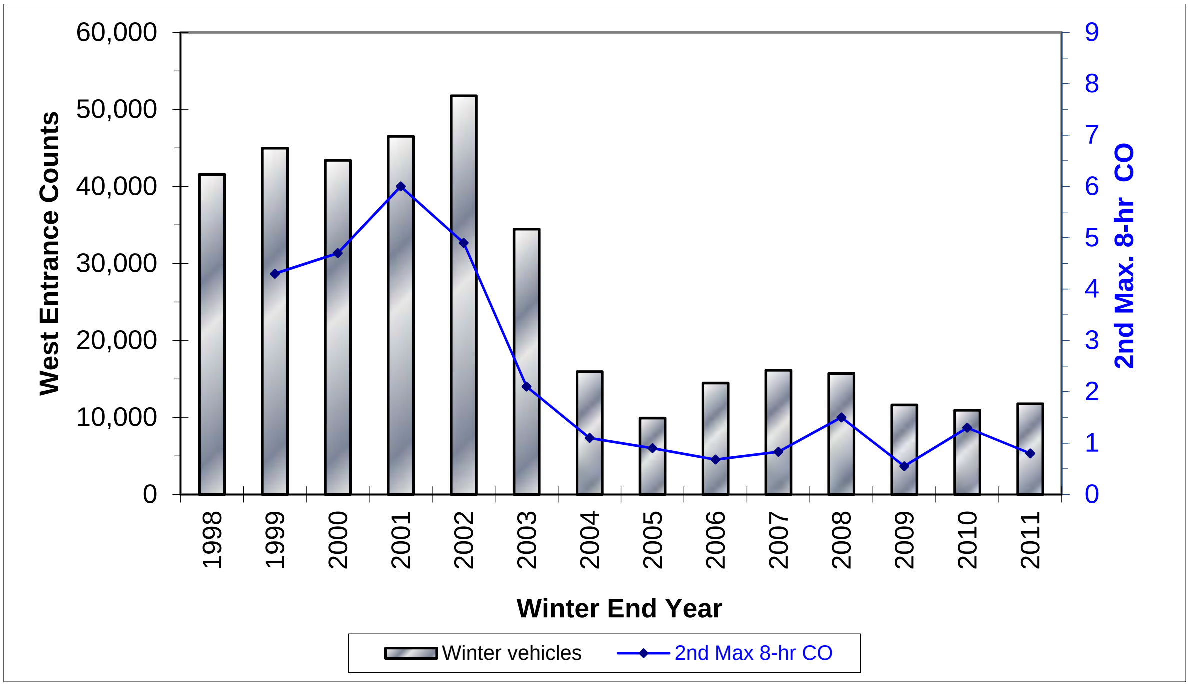

Figure 3. A comparison of the winter season OSV traffic volume through the West Entrance and one metric for the air quality, the second highest daily concentration of the CO 8-hour average in ppm.

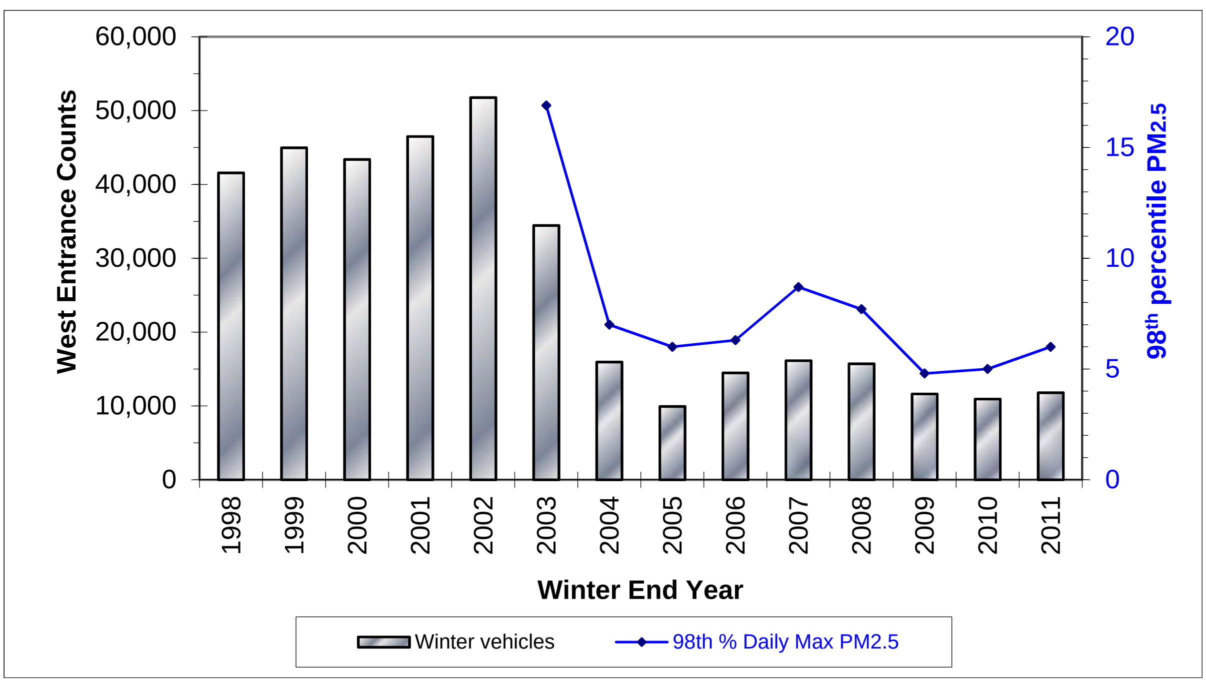

Figure 4. A comparison of the winter season OSV traffic volume through the West Entrance and one metric for the particulate matter air quality, the 98th percentile of the winter season daily average concentration.

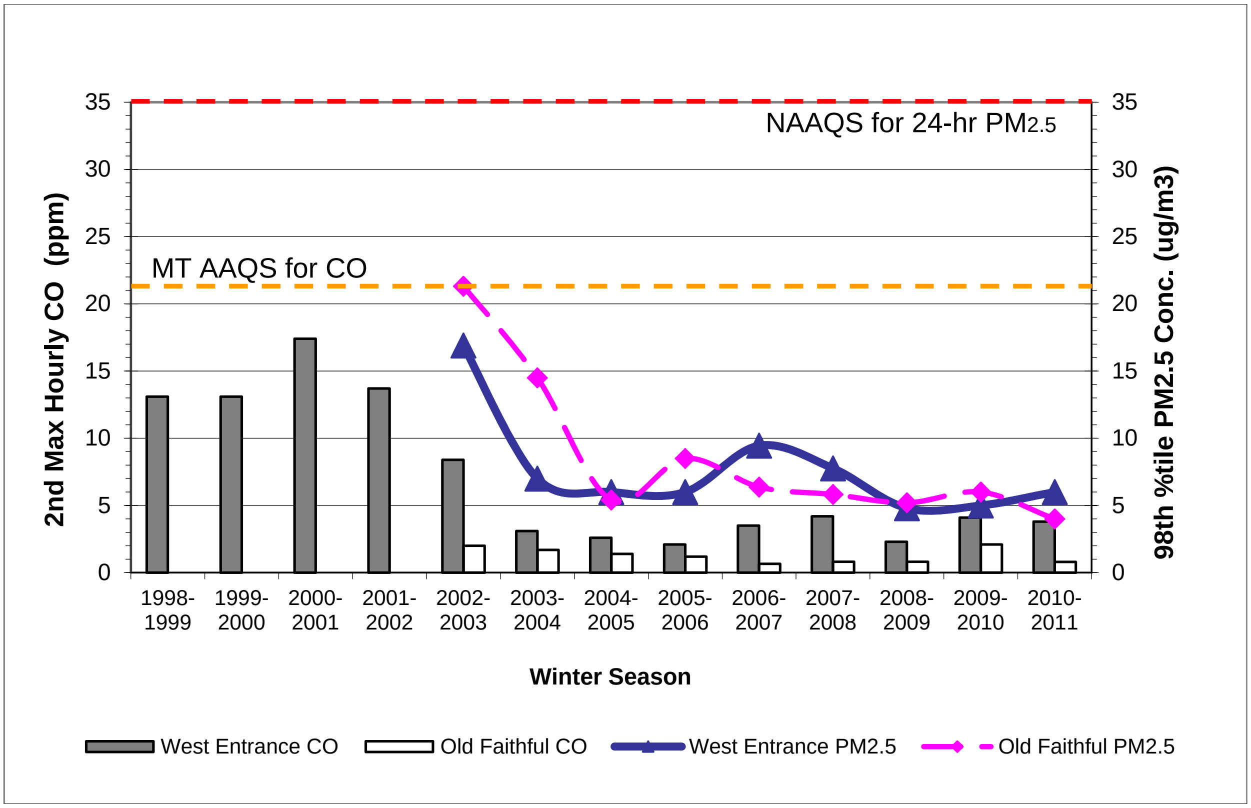

Figure 5. CO and $PM_{2.5}$ metrics for winter season air quality for comparison by year for the West Entrance and Old faithful sites. CO concentrations are bars (left axis) and the $PM_{2.5}$ are lines (right axis).

In recent years at Old Faithful the hourly CO concentrations are generally 1 ppm or less; 90 percent of the time the CO concentrations are 0.2 ppm or less. The $PM_{2.5}$ concentrations have remained nearly the same for the last three winter seasons (Table 3, Figure 5) and are now close to the same as at the West Entrance station (Figure 5). The timing in peak $PM_{2.5}$ at Old Faithful still differs from when the peak OSV traffic is present and in that regard differs from the observations at the West Entrance. Both the CO and $PM_{2.5}$ at Old Faithful are well below the NAAQS.

Winter air quality at the West Entrance and Old Faithful is primarily influenced by emissions from 4-stroke snowmobile and snowcoach engines. Some smoke and pollutants are transported from town and the nearest housing units to the park entrance area when the winds are from the west, as indicated by pollutant hours during hours when no OSV's are present. By contrast, the monitor in the city of West Yellowstone serves as a reference for conditions where 2-stroke snowmobile traffic dominates and there is a mix of wheeled vehicles and residential heating as additional CO and $PM_{2.5}$ sources. Note that the $PM_{2.5}$ concentrations in the city of West Yellowstone are much closer to the NAAQS (Table 3), possibly because of the greater CO emissions from 2-stroke engines in the snowmobiles and wood smoke. CO is elevated within the city of West Yellowstone and higher than at the park's west entrance, but does not approach the

CO NAAQS. The higher concentrations of air pollutants at the West Yellowstone city center are the result of more activity and more sources.

Diurnal patterns in CO and $PM_{2.5}$ are different for the three stations reflecting the different traffic patterns. The West Yellowstone city center diurnal pattern (Figure 6) has a morning peak and a secondary peak that tails into the evening hours. The evening pattern does not follow traffic. It does correspond to wood smoke from residential heating as the source of the $PM_{2.5}$, especially during the evening hours when there is very little snowmobile travel in West Yellowstone. Atmospheric boundary layer conditions may also influence the observations.

The West Entrance pattern shows a morning and afternoon peak in CO and NO_2 (Figure 6). The $PM_{2.5}$ has a different pattern with a peak after noon and a smaller peak after sunset in the evening. The West Entrance $PM_{2.5}$ does not correspond to traffic (low traffic at noon) and is not correlated to CO and NO_x air pollutant concentrations. This suggests a separate source. The $PM_{2.5}$ observed at the West Entrance during the evening, when there is no OSV traffic, is likely from smoke transported from town.

Old Faithful has yet another diurnal pattern that was explored in some detail in previous reports (Ray, 2008). CO at Old Faithful follows OSV presence and activity. At Old Faithful, CO concentrations peak during mid-day when OSV's are present while the $PM_{2.5}$ concentration are low. $PM_{2.5}$ concentrations go up at night after the OSV traffic has departed; $PM_{2.5}$ appears to be from local activities related to structural heating and cooking activities (Figure 6)

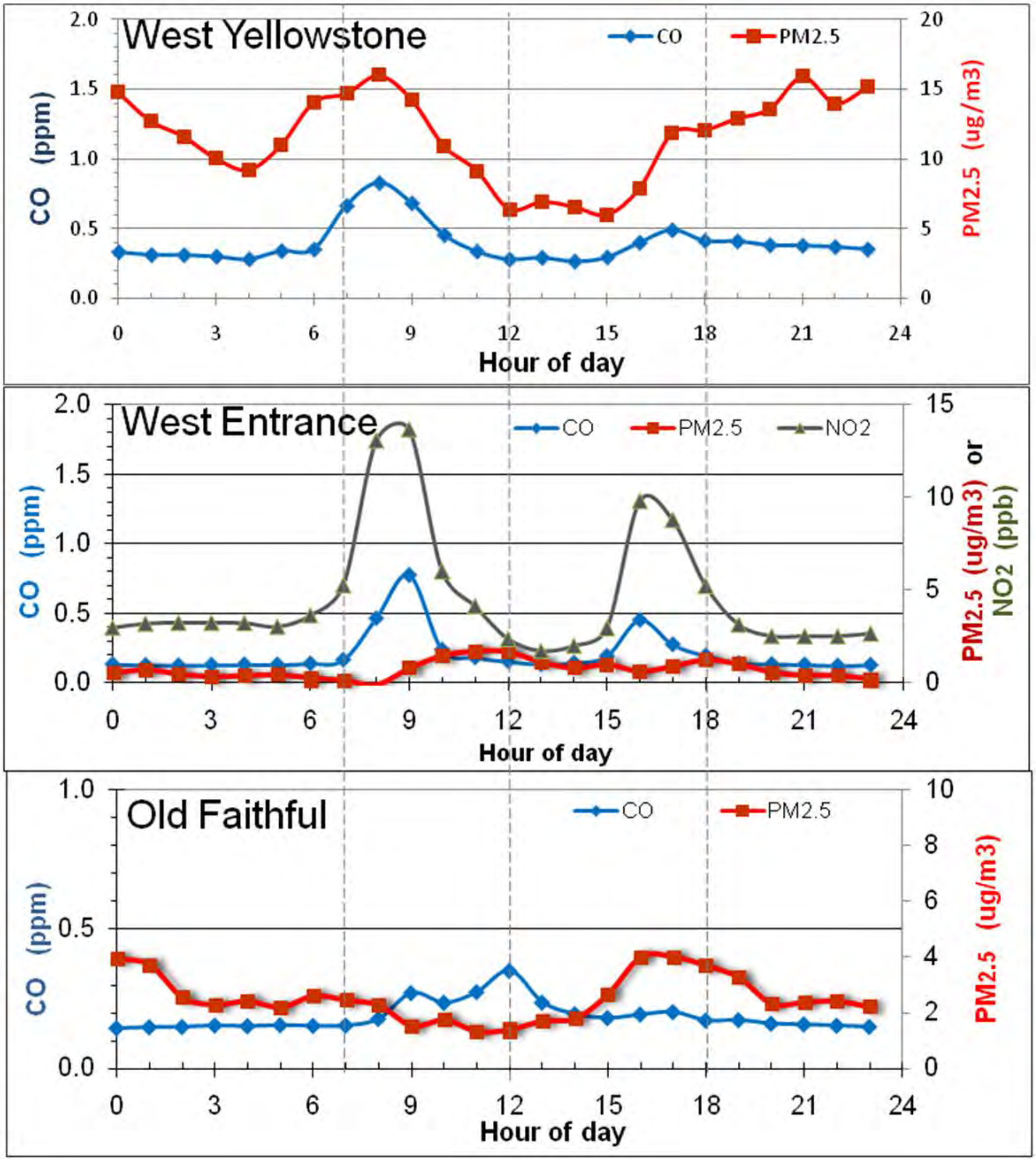

Figure 6. A comparison of the diurnal concentration means by hour of day for winter 2010–2011 for West Yellowstone, the West Entrance, and Old faithful. CO and NO_2 peaks correspond to peaks in daily snowmobile traffic. Note the scale changes.

Road-side NO_x measurements

The NO_2 road-side measurements were made near the exit side of the road (north side) at the West Entrance. The diurnal pattern of NO_2 is two peaks per day at 9 am and at 5 pm. The second peak tends to be higher. This is consistent with the emissions being on the road closer to the shelter during the exit periods, hence, closer to the analyzer inlet. The seasonal pattern has higher NO_2 during the winter when OSV are present and lower during the summer when only wheeled vehicles are in use. This reflects the lower emissions of NO_x by wheeled vehicles. Figure 7 shows this pattern. Winter 2009–2010 NO_x data includes only the second half of February and the first two weeks of March. Winter 2010–2011 includes the whole Dec. 15 to Mar. 15 period. As a percentage of the NAAQS standard, NO_2 is a larger percentage than either CO or $PM_{2.5}$. NO_2 emissions are considered a "moderate" concern according to the NPS air pollution impairment document. This is considered an "emerging issue" and NO_2 will continue to be monitored as part of adaptive management.

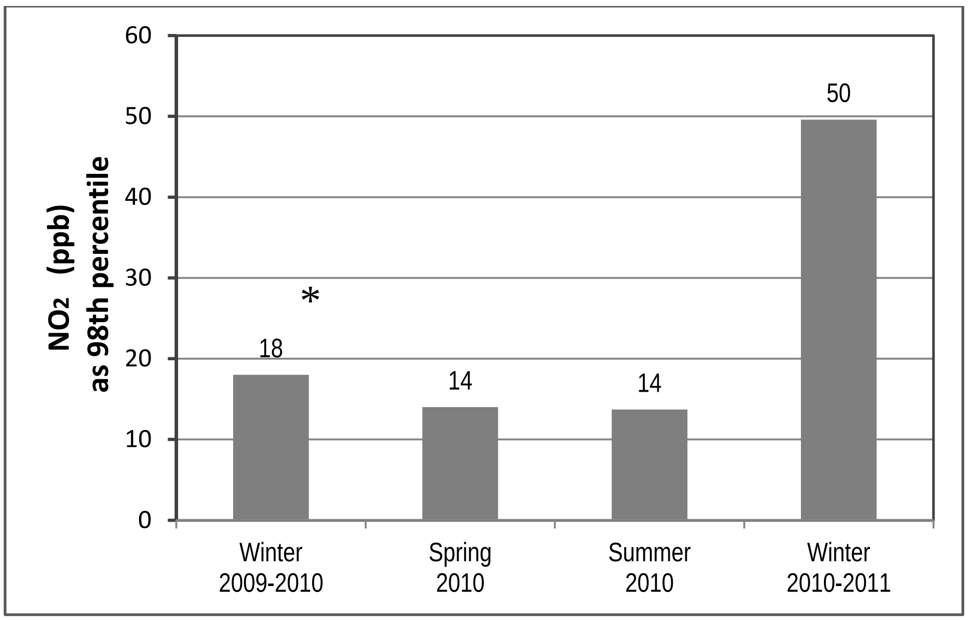

Figure 7. Comparison of NO_2 road-side concentrations at Yellowstone NP, West Entrance over different seasons expressed as the 98th percentile of the daily maximum 1-hour concentrations.

* Winter 2009–2010 data covered only Feb. 12 to Mar. 15, 2010. The standard is 100 ppb as a daily 1-hour concentration.

Seasonal Variations in air quality

The winter CO is disproportionately higher compared to traffic volume in the winter. This is illustrated in Figure 8 for summer and winter CO at the West Entrance compared to traffic volumes. The gray bars are seasonal maximums of the daily maximum 8-hour average CO. The white bars and black bars are West Entrance seasonal traffic counts for summer and winter respectively. In 2007 and 2008 there were summer wildfire events that increased the CO and

$PM_{2.5}$ concentrations during several day periods. Not much difference in CO is seen from winter to summer when the wildfire events are absent in the summer. There is a very large difference between the number of summer wheeled vehicles and the number of winter OSV. The summer CO pollutant amount does not appear to follow the trend of increasing wheeled-vehicle traffic because of the lower CO emission rates of wheeled vehicles and additional summer vertical mixing of the atmosphere.

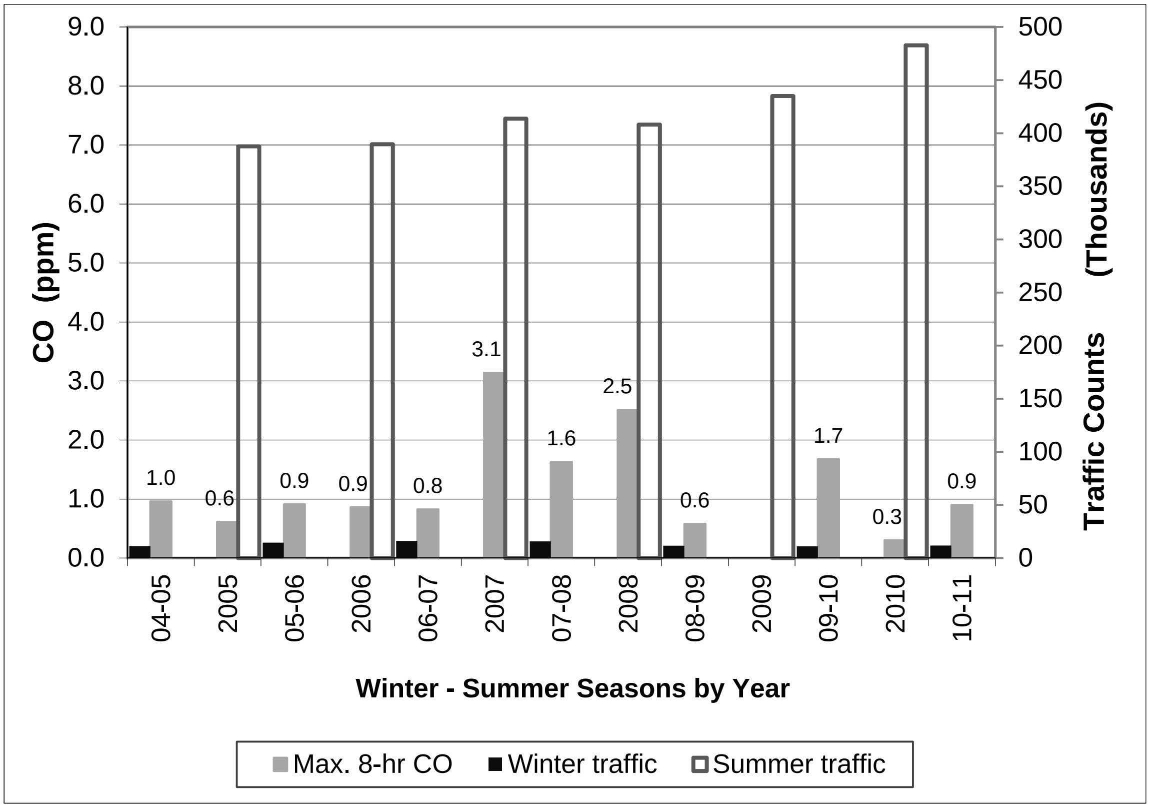

Figure 8. Air quality expressed as maximum daily 8-hr CO (gray solid bars) by season compared to the seasonal traffic counts (solid black bars winter and open bars summer).

Seasonal differences are explored more in Figure 9 for the three monitoring sites. The seasonal differences in ambient CO concentrations relate to the type of traffic. In Figure 9 the winter CO concentrations, expressed at the maximum seasonal and as the 90th percentile of the season concentrations, are generally higher than in the summer when there is wheeled-vehicle traffic. The exceptions are summers when smoke and other emissions from wildfire are present and are effecting air quality. Several other points from Figure 9: the cleanest of the 3 sites is Old Faithful, followed by West Entrance, and the city center site in West Yellowstone. All three sites are above the background expected for CO of about 0.13–0.15 ppm.

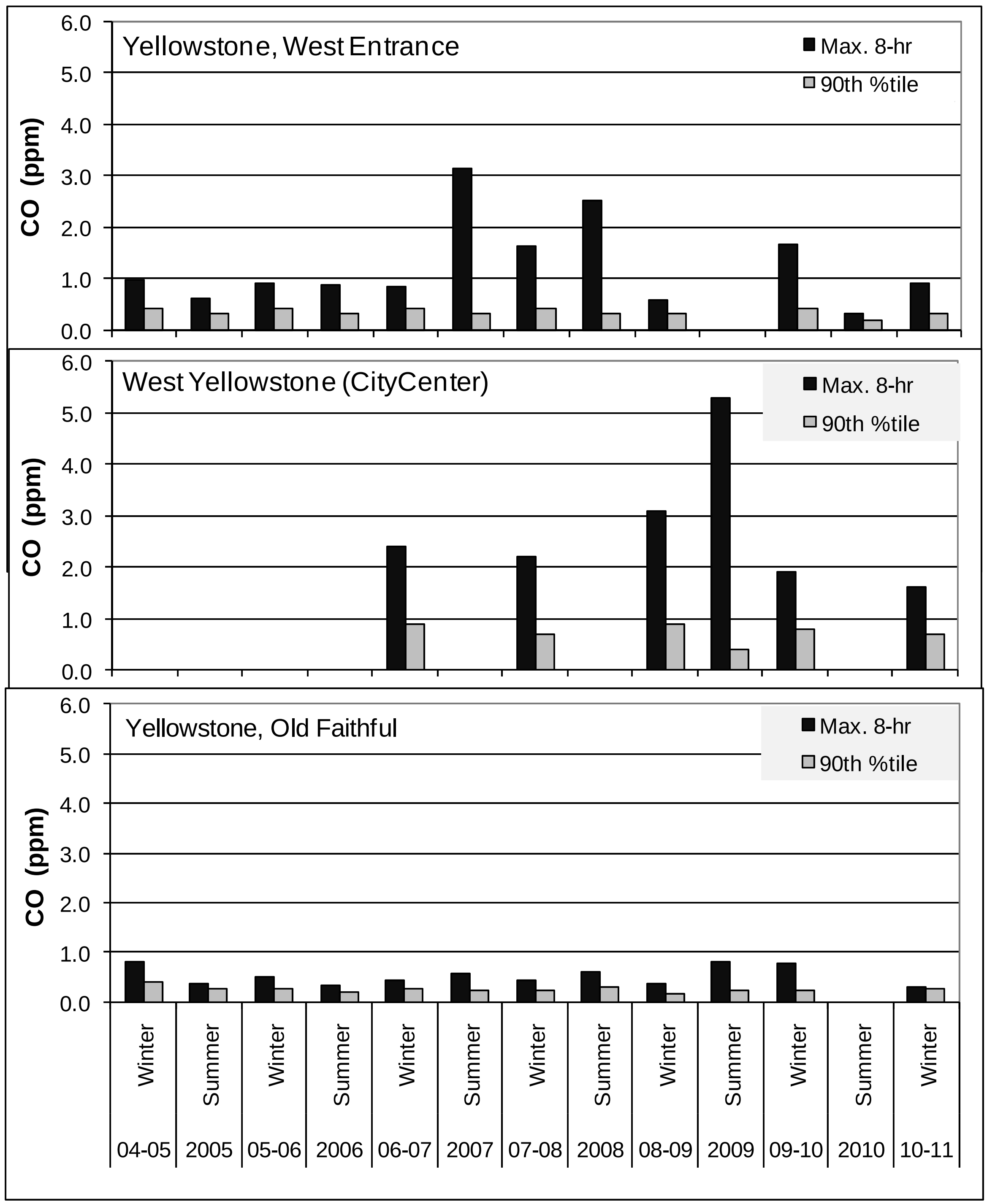

Figure 9. A comparison of CO concentrations by season for the two Yellowstone monitoring locations that have OSV traffic and the West Yellowstone city center location.

Air quality related to traffic volume

The relationship between OSV entry counts and the observed CO concentrations is explored below in Figure 10. The linear relationship is derived from the west entrance OSV counts using 10-minute average data for both the CO monitor and the traffic counter. Weather conditions such as wind direction and speed, temperature, snow, and boundary layer height affect the dilution of the local emissions near the gate so that observed CO concentrations vary from day to day. The upper line represents the change in the highest CO concentrations as traffic increases during the 2009–2010 winter morning "rush hour" period. The lower line is the mean change in CO concentration with increasing traffic. The maximum CO concentrations are more variable and increase more rapidly than does the mean concentration. Thus, as an example, a doubling of OSV traffic increases the maximum CO by 70% but the mean by only 30%. The gray area is where the higher CO concentrations are predicted as the number of OSV through the west entrance changes.

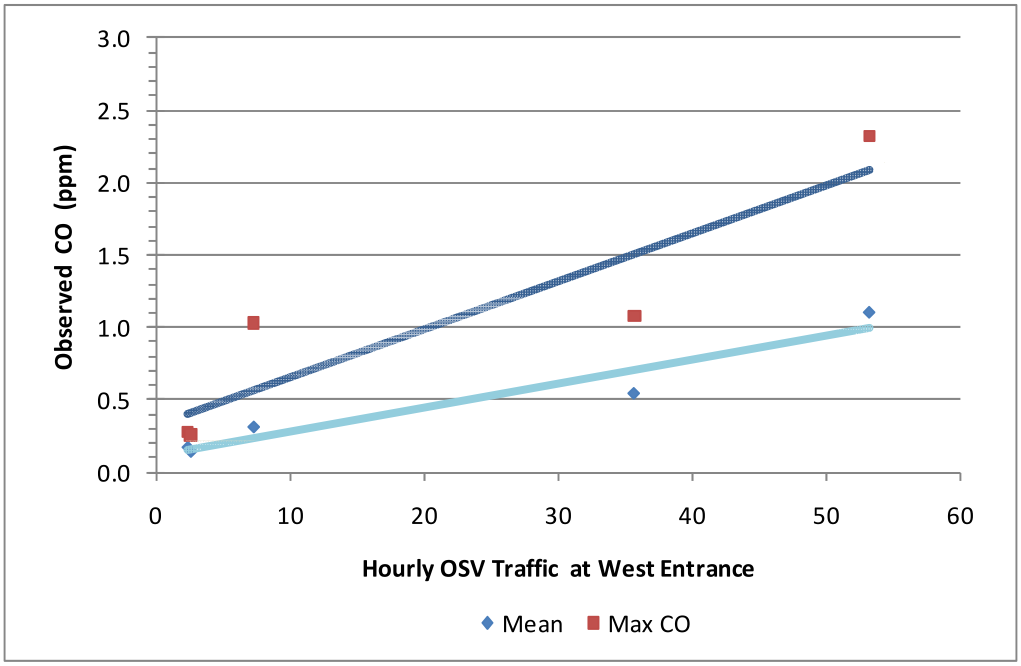

Figure 10. Relationship of hourly average traffic volume at the West Entrance with the observed CO concentrations. The graph uses monitoring data from the winter 2009–2010 mix of BAT snowmobiles and unregulated-emission snowcoaches.

Modeling comparison to observations

Scenario modeling was used for the 2007 EIS (NPS, 2007) to predict emission levels and concentrations under what was considered the worst weather conditions for air quality. Emission rates for snowmobiles and snowcoaches were taken from the literature values then available. Since several different traffic levels were modeled; it is possible to extract some information about the expected changes in pollution concentrations with traffic volume. In this exercise, it was assumed that the modeling results are proportional to the emissions of the vehicles and that an "equivalent snowmobile" emission level could be used for snowcoaches. This is to account for the different mixes of snowcoaches to snowmobiles. The model run with snowcoaches only and the emission rates for snowcoaches were used to calculate how many equivalent BAT snowmobiles each snowcoach represented. The results are plotted in Figure 11 for both the 1-hour CO and the 8-hour CO at the West Entrance. For reference an equivalent curve for 2-stroke snowmobiles has been added. The steeper the slope of the line, the more emissions there are per OSV. All the model lines have intercepts close to the CO background concentrations. The key point from both the observation and the dispersion modeling approaches represented in Figures 10 and 11 is that increasing numbers of either snowmobiles or snowcoaches will increase the air pollutant concentrations. If the emission levels of either type of OSV are reduced then the effect of more traffic would be reduced.

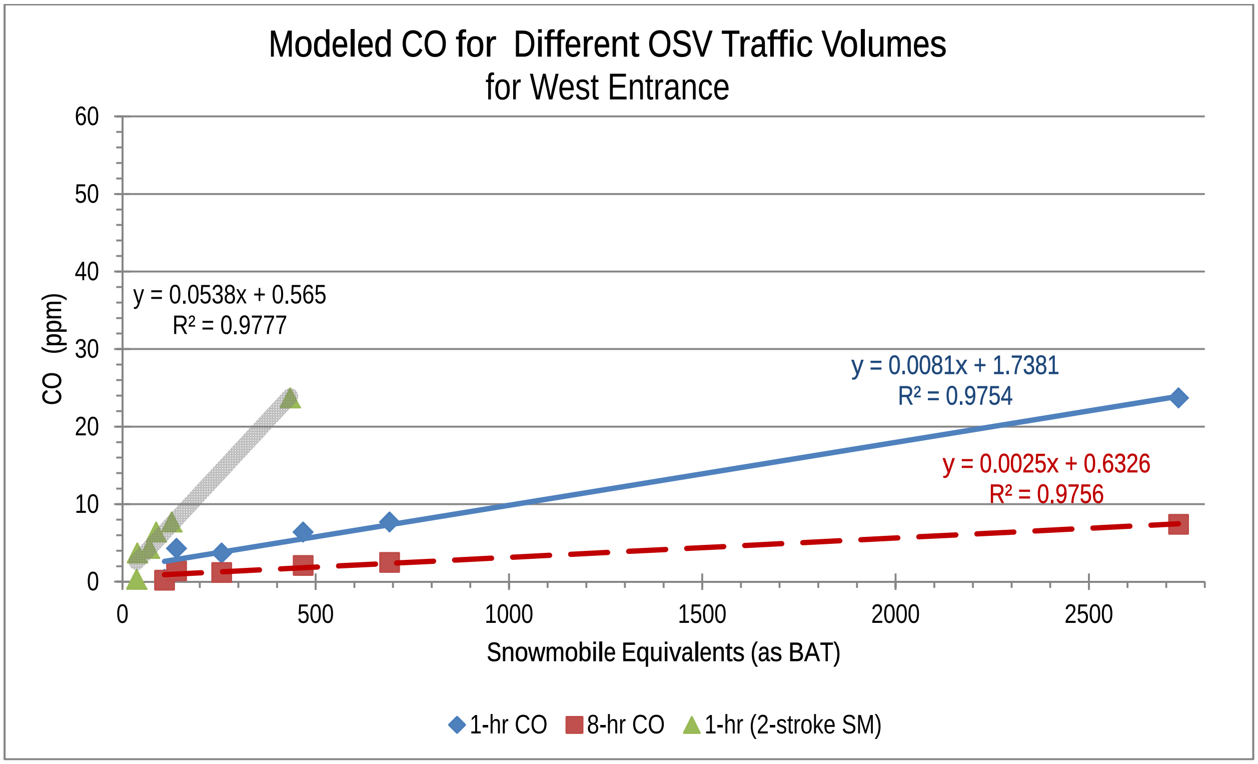

Figure 11. Estimates from modeling of the effect on ambient air quality for CO with changes in daily snowmobile volume. Calculated from scenario runs with snowcoaches converted to equivalent-emission numbers of 4-stroke snowmobiles. 2-stroke (non_BAT) snowmobiles (thick gray line) are shown for comparison.

The emission factors used in the modeling set the NO_x emissions proportional to the CO emissions from each type of OSV. An estimate of the expected NO_x concentrations can be calculated based on CO concentration measurements. Since the two pollutants are from the same sources, the concentrations tend to vary together based on the local dilution and traffic volumes. This is seen in the diurnal patterns where the timing of the peaks is the same. Although the CO range is a small percent of the CO standard, the NO_x ranges to 50% of the standard.

Some CO concentrations as a function of OSV traffic have been estimated for the morning period (Ray, 2008) based on a regression model of observation data. CO and NO_2 have been found to correlate very closely (R^2 = 0.78). Therefore, estimations of NO_2 based on what we have observed for CO gives an estimate of the effect of traffic on projected NO_2 concentrations (Figure 12). Based on model projections, more than 320 OSV per day would likely lead to exceedances of the NO_2 standard and poor, unhealthy air quality. There is a fair amount of uncertainty is this estimate, but OSV limits from the 2011 temporary winter plan or the scenarios in the 2011 EIS would likely lead to NO_x concentrations below the standard.

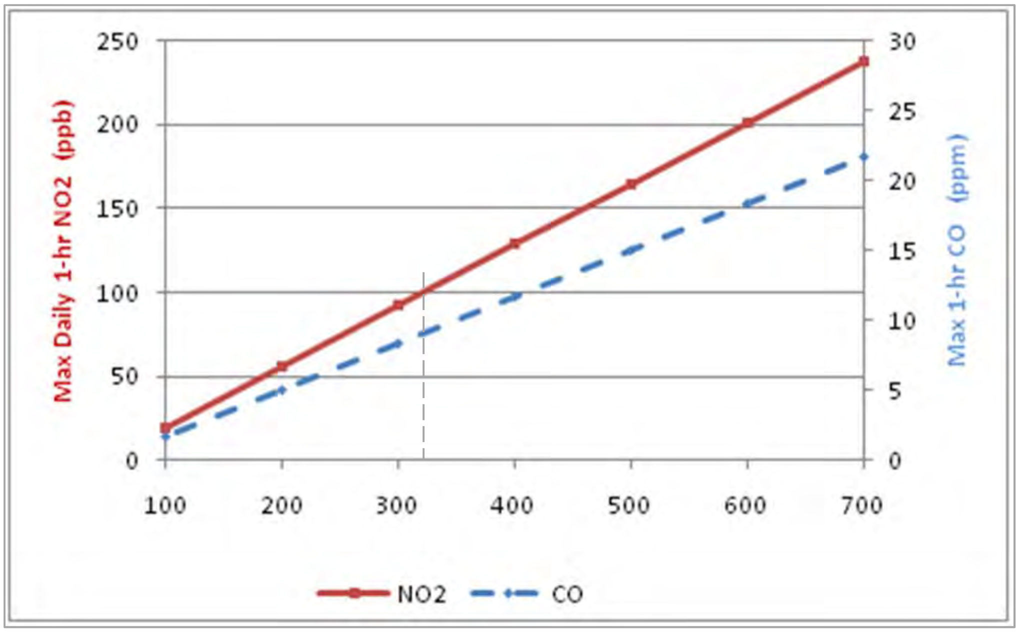

Figure 12. Estimated effect on observed NO_2 concentrations at the West Entrance with increase OSV traffic using relationships of observed CO concentrations to traffic volumes and the NO_x to CO ratios.

Winter traffic measurements

Winter traffic is counted by park staff at the entrance by type of vehicle and the daily totals summarized later. At the West Entrance a hand count of hourly entry by OSV's is done at the request of researchers. The guides and snowcoach operators hand the entrance staff paperwork that gives the company and number of visitors being taken into the park, however, this accounting material is handled separately. What is not obtained by the existing procedures is electronic vehicle counts, a complete list of operators and the vehicles they are bringing into the park, and a time resolution that resolves groupings of vehicles. A radar counter unit had been tested the last two winters, but the height and position of the sensor at the side of the road has not been right before.

Three methods for counting OSV entries were used at the West Entrance station in winter 2009–2010: 1. Manual counts by entrance staff (hourly), 2. Radar traffic counter (10 minute averages), and 3. Motion sensor activated digital camera (averaged to 10 minute intervals). The radar counter was mounted on a temporary tower set up at the correct distance and height from the road so that all lanes of traffic could be counted. Both entry and exit traffic was counted by the radar unit. It was also set to distinguish long vehicles (snowcoaches) from short vehicles (snowmobiles). The motion sensor triggered the camera for all entry traffic. A person had to go through all the images, identify duplicate images of the same vehicles and count vehicles per 10 minute interval. The camera images show vehicle type and often the vendor and model can be identified. This information was not used or recorded except to explore a few periods when there were high CO events.

Each method had its problems. Multiple recordings and math errors were discovered in the manual count method. Where cross-check methods could be used from the paper records, the manual counts were corrected. The radar unit had problems counting groups that stopped and then started again in the field of view. The closely spaced groups of snowmobiles were sometimes counted as snowcoaches. Entry numbers and exit numbers often did not match for the day, but are close, which may reflect the miscounting from entry vehicle grouping. Partly this was corrected by coning off areas so the OSVs could not stop in the radar-device field of view. To get the most out of the radar counter, the field of view must be set up properly and the unit adjusted to distinguish between short and long vehicles. The camera was excellent at capturing motion and an associated image. Counting from the low resolution images is a tedious manual operation that requires some care so vehicles aren't counted multiple times.

Comparison of counts by method

The three methods were compared using the daily totals where the manual entry counts were taken as the "true" traffic volume. Results for the full 2009–2010 season are shown in Figure 13. The radar counter tended to read low; the manual counts and the camera-counts were close. 10-minute camera counts were used to compare to 10-minute averages of the 1-min CO and NO_x data. Traffic vs. pollutant plots was constructed. Each day tended to have a different relationship. This is reasonable since wind direction and mixing heights also vary each day. Traffic relationships to air pollutants are summarized in different ways in Figures 11 and 12.

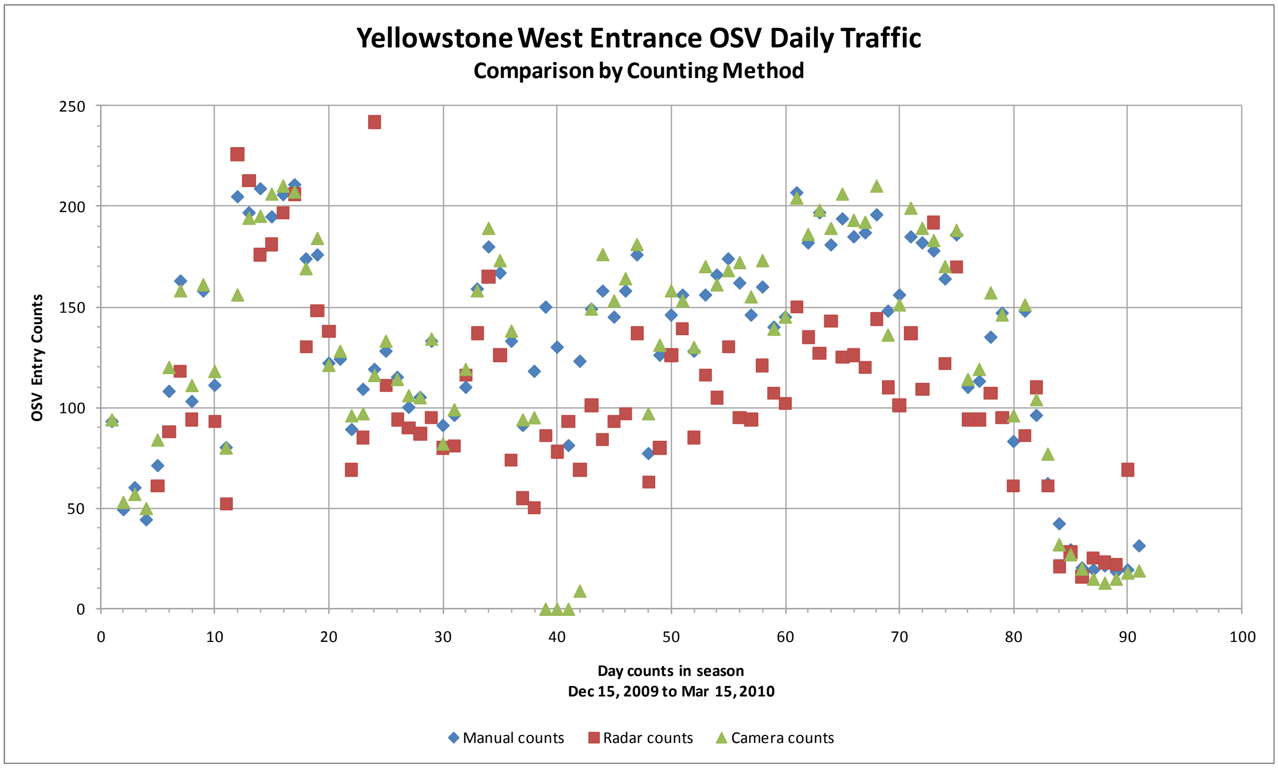

Figure 13. Comparison by day of the OSV entry counts at the West Entrance. The manual counts are blue symbols, the radar counter are red symbols, and the motion-sensor camera counter are green symbols. The manual tallies have generally been taken as the most accurate; however, errors occur even in this method.

Traffic patterns

From Dec. 22, 2010 to Jan. 3, 2011 the OSV traffic increased and was high for multiple days, except for Christmas Eve and Christmas day (Figure 14). OSV traffic also spiked around the Jan. 17 and Feb. 21 holidays. Snowcoach traffic mirrors snowmobile traffic except at about 1/6 the volume. Daily mean snowmobile traffic through the west entrance was 111 vehicles vs. only 19 for snowcoaches. The average number of administrative vehicles was only 9. As before, the daily counts of traffic were not good indicators of pollutant daily maximum concentrations. Often the highest pollutant concentration was in the late afternoon period when vehicles were exiting the park through the west entrance (see Figure 6). Typically, the OSV traffic travels faster during the exit than during entry and they do not stop at the gate.

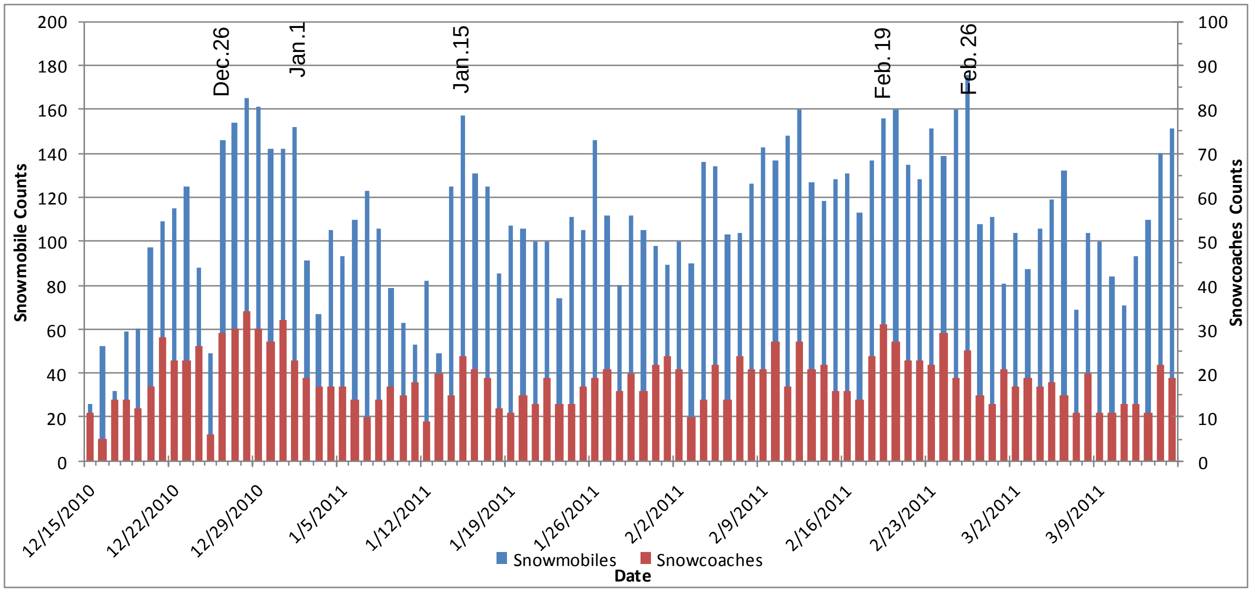

Figure 14. West Entrance manual traffic counts by gate staff show the daily changes through the winter 2010–2011 season and the volume of snowcoaches compared to snowmobiles. Highest counts are often around holidays.

Background $PM_{2.5}$ conditions – IMPROVE data

The $PM_{2.5}$ concentrations at the West Entrance and Old Faithful stations do not decrease to low values overnight during the winter (see Figure 6 for the pattern) and are higher than would be expected for the current background. CO concentrations on the other hand do go to low values overnight that are very close to the expected CO background (Figure 6). What is the $PM_{2.5}$ background that would be expected in Yellowstone? What does this difference in CO and $PM_{2.5}$ behavior indicate about night time emissions and transport? The long-term record from the IMPROVE station that is located away from the roads is used here to provide some answers to the questions posed above.

The IMPROVE station at Lake is isolated from the road for both summer and winter vehicle traffic. In summer there is more activity nearby because of the housing units just down the hill to the south. In examining the annual IMPROVE $PM_{2.5}$ data (Figure 15), there is not a long-term trend. Seasonal $PM_{2.5}$ can change considerably, especially during the summer when wildfire smoke can produce large short-term spikes (Ray, 2007). Unlike the $PM_{2.5}$ observed at the West Entrance, the minimum season is winter or Fall not Spring at the IMPROVE station (Figure 16, 17). The spring mean $PM_{2.5}$ concentration for 1996-2003 is 3.0 $\mu g/m^3$, but the winter mean is only 1.4 $\mu g/m^3$. Fall $PM_{2.5}$ is also low at 1.8 $\mu g/m^3$ (Table 8).

Seasonal data from other park $PM_{2.5}$ monitoring stations are only partially available and don't go back as far as the IMPROVE dataset. The $PM_{2.5}$ mass data for several locations is presented in Table 8. Old Faithful has $PM_{2.5}$ at higher concentrations than the Lake IMPROVE site for winter, which is probably due to the area and mobile sources of $PM_{2.5}$ at Old Faithful (Ray, 2007). The West Entrance site and especially the city center station in West Yellowstone see much higher

$PM_{2.5}$; these stations are next to roads with mobile sources. It has been pointed out previously that $PM_{2.5}$ is high at the West Entrance (Ray, 2007) and can be related to the winter vehicle traffic (Figure 4). It seems reasonable to consider the 1.4 µg/m^3 observed in winter at the IMPROVE as a practical regional background concentration. That would make the average winter $PM_{2.5}$ 420% above the background at the West Entrance and 215% above the background at Old Faithful. The peak winter concentrations of $PM_{2.5}$, seen when there is traffic at the park monitoring stations, are 5 to 10 times the background (using the 98th percentile).

The seasonal pattern and amount of variability from year to year in the $PM_{2.5}$ at the IMPROVE station can be seen in Figures 15 and 16. Overall, there is no trend in the annual $PM_{2.5}$. Low $PM_{2.5}$ values are seen each winter and higher values in other seasons. The $PM_{2.5}$ concentration at the IMPROVE monitoring station are below national ambient air quality standard of 35 µg/m^3. Higher concentrations (Table 8) and more frequent winter $PM_{2.5}$ events are seen at Old Faithful and West Entrance stations (Ray, 2007).

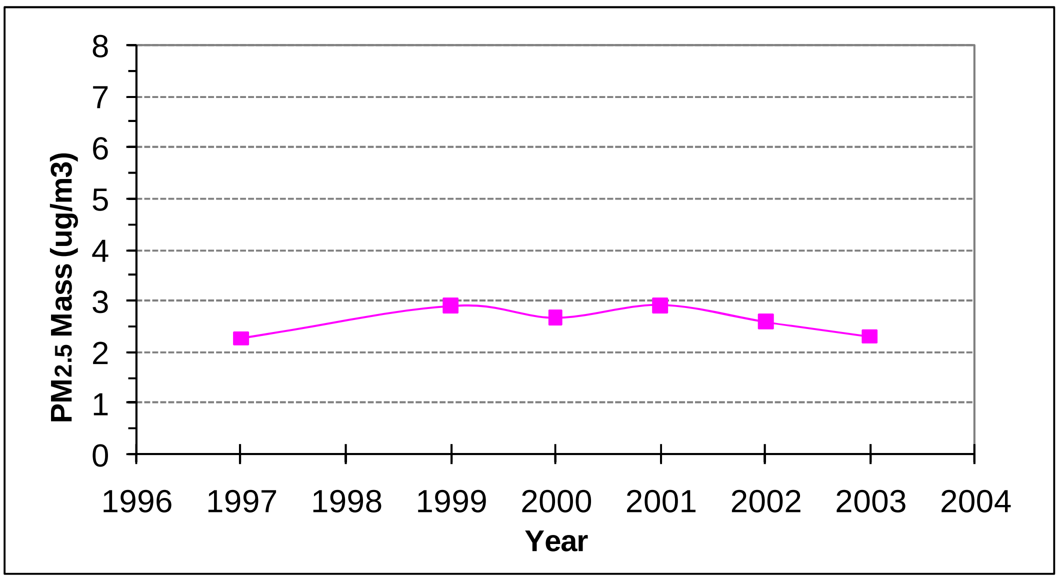

Figure 15. Annual mean $PM_{2.5}$ based on IMPROVE 24-hour samples taken every 3rd day at the Yellowstone water-tank station. No trend is seen over this period.

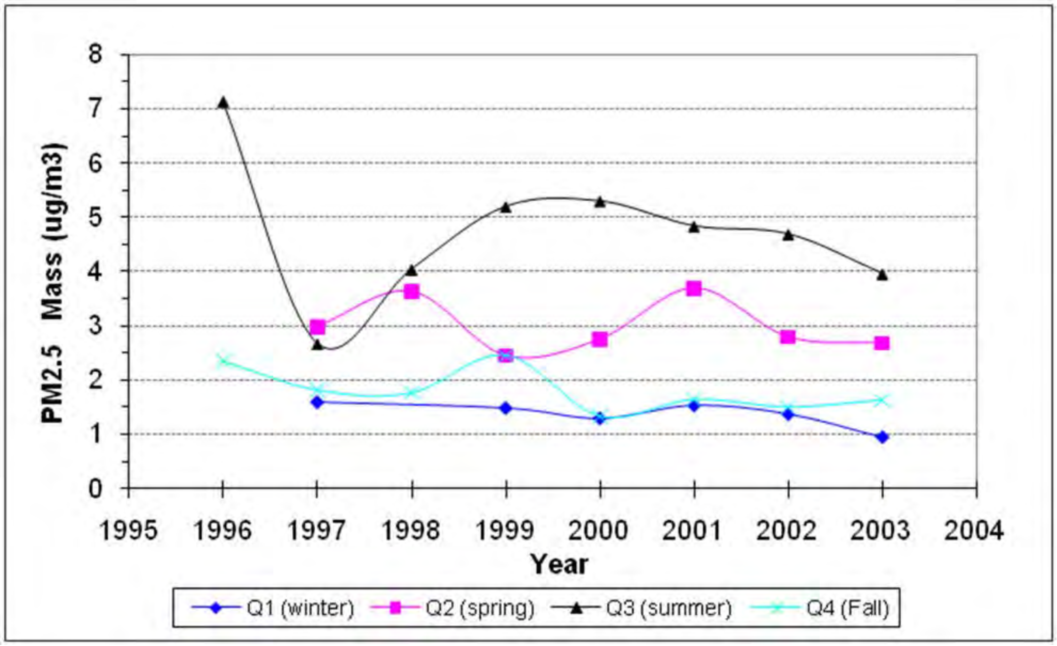

Figure 16. Quarterly mean $PM_{2.5}$ concentrations from IMPROVE for Yellowstone, Lake water tank site. Winter and fall have the lowest average concentrations.

Table 5. Seasonal mean $PM_{2.5}$ concentrations from the Lake Village (water-tank) IMPROVE station for the period 2000–2010 compared to other measurement locations.

Season	2000-2010 Lake IMPROVE, water tank			2009–2010 West Entrance			2009–2010 town of West Yellowstone			2009–2010 Old Faithful		
	Max. daily	98th %tile	seasonal mean	Max. daily	98th %tile	seasonal mean	Max. daily	98th %tile	seasonal mean	Max. daily	98th %tile	seasonal mean
Winter	5	3	1	12	10	6	39	35	13	6	5	3
Spring	10	5	3	7	7	5	14	14	7	6	6	4
Summer	25	11	5	16	11	7	15	11	5	9	9	4
Fall	8	4	2	9	9	6	21	21	13	4	4	3

When the seasonal $PM_{2.5}$ is compared between sites, several important differences are evident. First, $PM_{2.5}$ concentrations at the roadside sites at the West Entrance and city center are higher in winter than at the Yellowstone IMPROVE site. Old Faithful $PM_{2.5}$ concentrations are only slightly higher than at the IMPROVE background site. There is little seasonal difference at Old Faithful, except for summer which is known to be influenced by wildfire smoke. The West Entrance and city center sites have the highest $PM_{2.5}$ in winter and are lower in all other seasons. Winter and part of the fall have residential wood smoke and OSV traffic nearby that effect these two monitoring sites

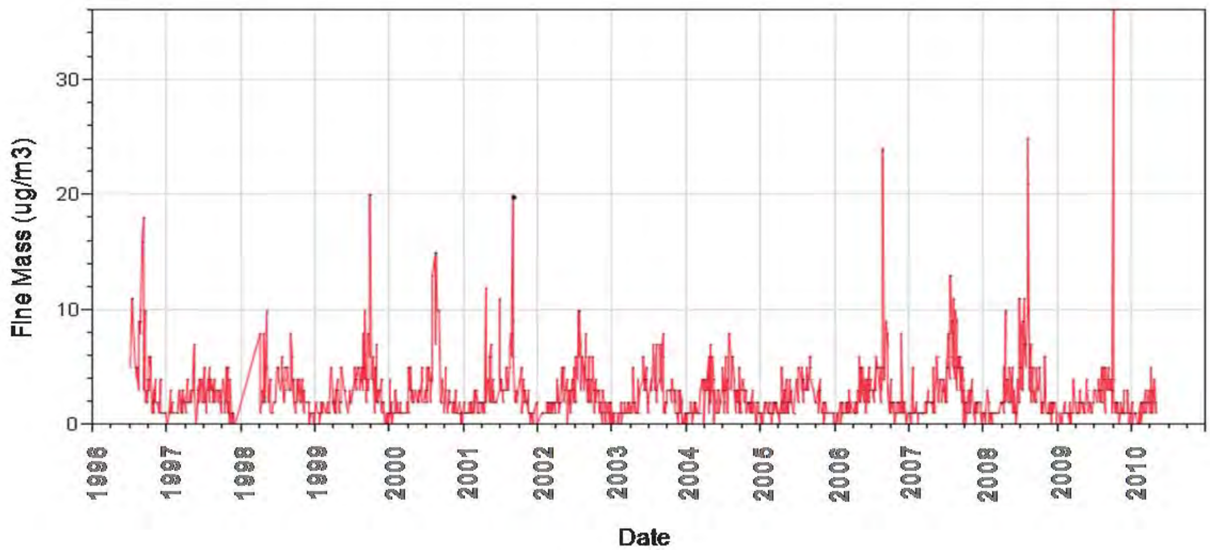

Figure 17. Each 24-hour filter sample for $PM_{2.5}$ is plotted from 1996 to 2010 for the Lake IMPROVE station (water tank site). Winter minimums and summer highs are seen in each year. The very high spikes are summer events, usually wildfire smoke.

The Winter-Summer annual pattern is repeated every year (Figure 17). The lowest $PM_{2.5}$ concentrations at the background IMPROVE site (water tank) are during the winter. The greatest variability is during summer, depending on what wildfires happen. Winter background $PM_{2.5}$ is about 1-2 µg/m^3. The winter monitoring program stations at the West Entrance and at Old Faithful have concentrations well above the expected winter background $PM_{2.5}$ concentrations.

The IMPROVE $PM_{2.5}$ data for winter can be used as an approximation of the region background concentration. Although the $PM_{2.5}$ concentrations have come down as limits and controls have been implemented in the park on winter vehicle traffic, the $PM_{2.5}$ is still above the expected background. Figure 18 makes this point with a bar graph of mean $PM_{2.5}$ concentrations by monitoring station. The park monitoring stations have stabilized at $PM_{2.5}$ concentrations well below the standard and slightly above the background. The city center $PM_{2.5}$ is coming down slowly. Data from this site does not go back to pre-BAT years, thus there is not data to show what influence the increased number of 4-stroke snowmobiles had on West Yellowstone air quality.

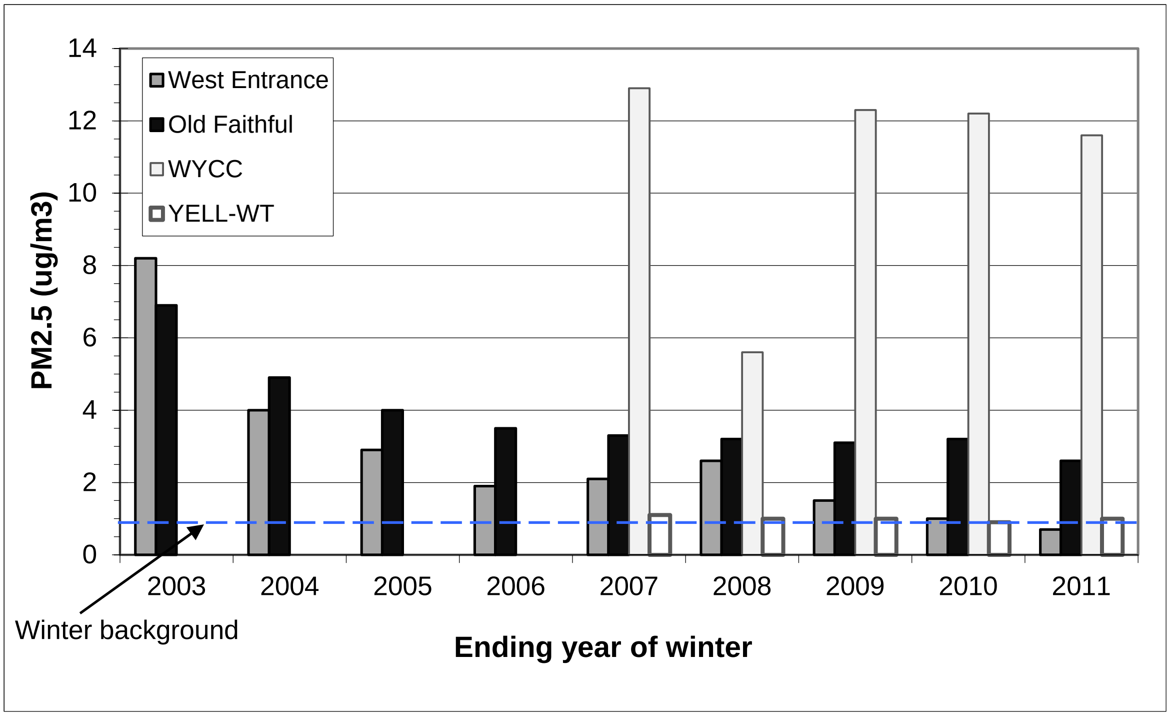

Figure 18. The average $PM_{2.5}$ at Old Faithful and the West Entrance has come down since the BAT requirement for snowmobiles was implemented and the number of snowmobiles entering the park reduced. Both sites are above the background concentration indicated by the IMPROVE monitoring station at a remote location in the park.

Conclusion

The air quality has remained relatively unchanged at the monitoring stations in Yellowstone National Park over the last 4-5 years. This is primarily the result of the requirement for Best Available Technology (BAT) snowmobiles (NPS 2008) and a much lower number of snowmobiles entering the park. Pollutant concentrations were slightly lower during the 2010–2011 winter than in the previous winters at the West Entrance. This partly reflects the lower number of OSV traffic during the 2009–2010 and the 2010–2011 winter seasons. The winter air pollutant concentrations remain below the health standards set by EPA for the locations where monitoring occurs.

NO_2 has become a new issue to consider. The new national standard is based on the maximum daily 1-hour concentration, as the 98^{th} percentile over a 3-yr period. At this point, the NO_2 is less than 50% of the standard and air quality is acceptable, but not ideal for a preserved natural area. Other studies and some monitoring in the park have shown that NO_x (and other pollutants emitted by vehicles using the roadway) drops off rapidly with distance from the roadway. Therefore, it is expected that the vast majority of the park is at background levels of less than 2 ppb NO_2.

More than one year of continuous NO_x and NO_2 data has been collected at the West Entrance station. The highest NO_2 concentrations are found during the winter when OSV traffic is present. It has been found that CO and NO_x vary together as expected from emission factors. The traffic vs. CO observation models was combined with the CO to NO_x correlation to produce an estimate of the number of OSV that would be needed on a daily basis for NO_2 to exceed the standard (Figure 12). The estimated number of OSV vehicles of 320 is well above proposed limits in winter use planning.

Detailed counts of entering and exiting OSV traffic were made at the West Entrance with a resolution of 10 minutes. This data was compared to ambient pollutant concentrations to get a relationship between the traffic and the air pollution. The correlation between traffic and $PM_{2.5}$ was poor at the West Entrance, however, a relationship was found for CO that varies daily depending on weather conditions. Based on the overall model, OSV traffic volumes could increase considerably, from a CO air pollutant standpoint, before violating the national CO standard or becoming a major impact (Figure 11) again. These models are approximations that give the general relationship between traffic and CO concentrations. As snowmobile and snowcoach fleets change over their emission levels will be different and the relationship will change.

The OSV entry counts have become a park management tool and are likely to become increasing important as policy is tied even more to the number, type, and timing of OSV entry. The motion-detection camera provided a good count and record of traffic with an overall error of about 1%. The procedure is labor intensive and usually done several days or months later, thus being of limited value as an immediate record of traffic volumes. The radar traffic counter provides more immediate access to counts, but under winter conditions and with traffic behavior patterns at the West Entrance, the undercount error was from 10-15%. It may be possible to improve the radar counter error by a slightly different placement so that all vehicles get counted. The radar counter can be used any place where there is power and communications links can be made.

With regard to future winter air quality monitoring at Yellowstone, data from the West Yellowstone city center monitor indicates that the air quality is worse in town. This station, which is outside the park, has served its purpose and can be closed down now that comparison values have been obtained. The Old Faithful station is now in a poor location for future monitoring because it is near the temporary winter parking that is no longer being used. This station should be moved to a site nearer OSV traffic or closed. The observed concentrations are just above background concentrations and will not track OSV use in the area. The West Entrance station is well positioned roadside and gives reliable indications of the impact on air quality by the OSV.

Literature Cited

Air Resource Specialists, 2009. Data Transmittal Report for the Yellowstone National Park Winter Use Air Quality Study, 2008-2009. Air Resource Specialists, Fort Collins, Colorado. Available from http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm

Bishop, Gary A., R. Stadtmuller, D. H. Stedman, and John D. Ray, 2007. Portable Emission Measurements of Snowcoaches and Snowmobiles in Yellowstone National Park, *J. Air & Waste Manage. Assoc.* **59**, 936–942 (2009). (www.feat.biochem.du.edu)

Federal Register, 2007. Rules and Regulations, Final Rule governing the winter use in three parks. Vol. 72, No. 239 / Thursday, December 13, 2007/ page 70781. Online. **(**http://www.nps.gov/yell/parkmgmt/upload/finalrule13Dec2007.pdf)

IMPROVE monitoring program, http://vista.cira.colostate.edu/improve/ . Accessed 2-18-2009.

National Park Service, Public Use Statistics, 2009. Yellowstone visitor and vehicle count statistics. U.S. Department of Interior, National Park Service, Washington, D.C. Online. (http://www.nature.nps.gov/mpur/)

Ray, J. D., 2007. Winter Air Quality in Yellowstone National Park: 2006 – 2007, Air Resources Technical Report NPS/NRPC/ARD/NRTR-2007/065. National Park Service, Fort Collins, Colorado. Available from http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm

Ray, J. D., 2010. Winter Air Quality in Yellowstone National Park: 2008 – 2009, Air Resources Technical Report NPS/NRPC/ARD/NRTR-2010/285. National Park Service, Fort Collins, Colorado. Available from http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm

NPS/NRPC/ARD/BRTR-2008/139. National Park Service, Fort Collins, Colorado. Available from http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm

Ray, J. D., 2008. Winter Air Quality in Yellowstone National Park: 2007 – 2008, Air Resources Technical Report EPA, 2008. National Ambient Air Quality Standards (NAAQS). U.S. Environmental Protection Agency, Washington, D.C. Online. http://www.epa.gov/ttn/naaqs/

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National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
Air Resources Division
PO BOX 25287
Denver, Colorado 80225

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