Greater Yellowstone Area Air Quality Assessment Update

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Abstract

The Greater Yellowstone Area Clean Air Partnership (GYACAP) has recently completed an assessment update of air quality in the Greater Yellowstone Area (GYA). GYACAP consists of air resource program managers and specialists for the National Park Service; U.S. Forest Service; Bureau of Land Management; U.S. Fish and Wildlife Service; the Departments of Environmental Quality in Wyoming, Montana, and Idaho; and the Idaho National Engineering and Environmental Laboratory. The primary purposes of GYACAP are to serve as a technical advisory group on air quality issues to the Greater Yellowstone Coordinating Committee (GYCC), provide a forum for communicating air quality information and regulatory issues, and coordinate monitoring between states and federal agencies in the GYA. In 1999, GYACAP prepared an air quality assessment document for the GYCC for purposes of identifying air quality issues, conditions, pollution sources, and monitoring sites; summarizing known information; and advising the GYCC on air quality issues at the time. Five years later, GYACAP identified the need to update the assessment with a focus on new information on the four primary air quality issues within the GYA: urban and industrial emissions, oil and gas development in southwest Wyoming, prescribed and wildfire smoke, and snowmobile emissions. This presentation will include a summary of the assessment update on the four main air quality issues in the GYA.

Purpose of the GYA air quality assessment update

The Greater Yellowstone Area Clean Air Partnership (GYACAP) consists of air resource program managers and specialists for the National Park Service (NPS); U.S. Forest Service (USFS); Bureau of Land Management (BLM); U.S. Fish and Wildlife Service; the Departments of Environmental Quality (DEQ) in Wyoming, Montana, and Idaho; and the Idaho National Energy and Environmental Laboratory. The primary purposes of GYACAP are to serve as a technical advisory group on air quality issues to the Greater Yellowstone Coordinating Committee (GYCC), provide a forum for communicating air quality information and regulatory issues, and coordinate monitoring between states and federal agencies in the Greater Yellowstone Area (GYA). The GYCC consists of park superintendents, forest supervisors, and wildlife refuge managers; it was created to allow better communication and more integrated management between the GYA land and resource management agencies.

The purpose of the assessment is to help GYA land managers maintain a basic understanding of air quality issues and help them address resources issues, foster partnerships, and secure funding. The assessment is not a decision document. It does not make resource management decisions, and does not replace analysis needed at the project level to fulfill the requirements of the National Environmental Policy Act (NEPA). The goal of the assessment is to update the GYACAP (1999) air quality assessment document with a focus on new information on the four primary air quality issues within the GYA. These include urban and industrial emissions; oil and gas development in southwest Wyoming; prescribed and wildfire smoke; and snowmobile emissions.

The GYACAP (1999) Air Quality Assessment Document was prepared to provide the GYCC with comprehensive GYA air quality information, including an air quality legal framework; GYA air quality issues; current and potential impacts on GYA air quality; GYA air quality monitoring and summary of known information; and needs and recommendations. This assessment is intended to be useful in agency planning documents, national forest plan revisions, and NEPA documents; in facilitating air quality information exchange; and in providing air quality information to the public and other agencies.

Urban and industrial emissions

Urban and industrial emissions consist of a variety of industrial, petroleum refining, gas transmission, agricultural processing, wood processing, mining, power generation, sand and gravel, and mining sources. Most of these sources produce emissions continuously, which can concentrate pollution in surrounding communities during inversions. The U.S. Environmental Protection Agency (EPA)'s AIRData base (EPA 2004a) was queried for the total permitted major stationary sources of industrial emissions, in 1999, for the Montana, Wyoming, and Idaho counties in and surrounding the GYA. Many of these emissions, particularly the Wyoming, Idaho, and Gallatin County, Montana, sources, can be transported to GYA lands. Montana has the largest number of permitted stationary sources and the highest total emissions of nitrogen oxides (NOx), particulates (PM_{10}), and volatile organic compounds (VOCs). Idaho has the largest amount of permitted sulfur dioxide (SO_2) and carbon monoxide (CO) emissions (see Table 1).

Table 1. Stationary-source industrial emissions near the GYA (tons/year).

	CO	NOx	PM_{10}	SO_2	VOCs
Montana	2,066	5,501	1,330	13,541	2,591
Wyoming	1,488	3,436	78	5,127	689
Idaho	11,438	1,733	1,465	14,880	51

The Montana sources are concentrated in the Billings/Laurel area, where the largest concentration of petroleum refining and other industrial sources in the Montana/Wyoming/Idaho area occurs. Prevailing western winds disperse these emissions predominantly to the east and away from the GYA. Periodically, east winds can cause "upslope" conditions that carry these emissions toward the Beartooth and Absaroka Mountains on the Custer and Gallatin national forests. These east winds, however, are usually associated with tight pressure gradients, and are highly turbulent, with robust mixing heights and dispersion energy. The Wyoming stationary sources are energy generation, mining/minerals, and natural gas processing and transmission in the southwestern part of the state; these will be discussed in detail later in this update. These industrial emissions, in combination with minor sources and the extensive drill-rig emissions in southwest Wyoming, are the major air quality concern in the GYA. The Idaho sources are dominated by chemical and fertilizer manufacturing facilities in the Soda Springs and Pocatello areas, which can cumulatively combine with the energy-related sources in southwest Wyoming.

The EPA AIRData base (EPA 2004b) was also queried for currently listed non-attainment areas. These are geographic areas that have periodic violations of National Ambient Air Quality Standards (NAAQS). The non-attainment areas in proximity to the GYA include Billings, Montana, for SO_2, and Pocatello, Idaho, for PM_{10}. No non-attainment areas around the GYA occur in Wyoming, as the only listed Wyoming non-attainment area is Sheridan (for PM_{10}).

Greater Yellowstone/Teton Clean Cities Coalition

The U.S. Department of Energy's formal "Clean Cities" designation for the Greater Yellowstone/Teton Clean Cities Coalition (GYTCCC) occurred on September 18, 2002. This event marked an important milestone in the energy and transportation direction of the Greater Yellowstone region. After nearly five years of collaborative effort, the achievements of regional public and private organizations were formally recognized when the GYTCCC became the only designated "Clean City" in Idaho, Montana, or Wyoming.

This coalition is distinguished by the scope and diversity of its stakeholders, including three states, five national forests, two national parks, seven communities, and six counties, as well as dozens of private organizations. The majority of the existing U.S. Clean Cities are based in urban regions, where air quality serves as a primary driver for the initiative. The Greater Yellowstone/Teton region does not represent a city, but rather a focus on environmental protection and reduced energy consumption. The coalition has coordinated a number of projects that ordinarily would be beyond the scope of a single community or organization.

The primary thrust of the coalition is to reduce stationary and mobile air pollution sources. In 1999, Yellowstone National Park (YNP) and some surrounding communities began the switch to cleaner-burning, renewable fuels. All public and administrative refueling stations began dispensing only ethanol-blended fuel (unleaded). The Montana DEQ estimates that since the switch, YNP has reduced CO emissions by more than 50 tons. In 2001, YNP switched its entire diesel fleet (more than 300 vehicles) to biodiesel-blend oil (canola). Additionally, all standby generators and boilers within the park were switched to biodiesel-blend oil. A public biodiesel pump has opened in West Yellowstone, Montana, and another is slated to open in Belgrade, Montana, later this year (2005).

In 2004, YNP was the recipient of four donated, hybrid vehicles from Toyota. These Toyota Prius vehicles are used for outreach and education purposes to help visitors understand the latest in hybrid technology. Several of the GYA national forests are also beginning to use alternate fuel vehicles such as propane and hybrids.

Yellowstone National Park continues to seek funding to purchase more vehicles known as the new "yellow buses." The first (current) generation of yellow buses runs on biodiesel and meets forthcoming EPA diesel emission requirements. Propane and natural gas versions are being developed and will be used in the future. The buses will be introduced in the GYA for mass transportation and a shuttling service. They will also play a pivotal role in the creation of a rural tour district. Eventually, the tour district will not only be capable of moving visitors throughout the region, but also could be utilized to transport local residents. The first "leg" of the tour district will be a shuttle service from Driggs, Idaho, to Jackson, Wyoming, over Teton Pass. This will eliminate thousands of private commuter vehicles (and associated emissions) from that stretch of highway each day. More information on the Greater Yellowstone/Teton Clean Cities Coalition is available at <www.eere.energy.gov/cleancities/>.

Oil and gas drilling and production: southwest Wyoming

Oil and gas development is rapidly expanding in south-central and southwest Wyoming. High demand and high market prices have stimulated considerable interest in additional natural gas development within the Upper Green River Basin. Development of new gas resources is consistent with the Comprehensive National Energy Strategy announced by the U.S. Department of Energy in April 1998, and meets the purpose and need of the Energy Policy and Conservation Act. Increasing energy development results in increased emissions. Management of these energy development emission increases is currently the most pressing air quality issue in the GYA.

The Upper Green River Basin has about 2,900 existing wells listed with the Pinedale District Field Office, which is the most active BLM field office in the U.S. for gas development activity. Recently, the Pinedale office has processed 200–300 wells per year. About 425 new wells will be processed in 2005, and 475 in 2006 and 2007. The BLM Pinedale Resource Management Field Office is preparing a revision of its Resource Management Plan. Up to 8,700 new wells may be proposed within the Pinedale area.

As long as natural gas and condensate prices remain high and technology advances to improve recovery, it is expected that development of current fields will continue, as will the exploration for other gas deposits in the Upper Green River Basin. Compliance with NAAQS and prevention-of-significant-deterioration (PSD) increments, and protection of air-quality-related values (AQRVs)—particularly visibility—will require continued cooperation of the

USFS, NPS, BLM, Wyoming DEQ, and energy development companies.

Natural gas development is active in the Jonah II and Pinedale Anticline natural gas fields. Proposed new developments include the Jonah Infill, Pinedale Anticline Infill, South Piney coalbed methane, Riverton Dome gas, and Atlantic Rim gas. Additional development is likely north of the Pinedale Anticline in the Daniel area.

Wyoming DEQ air resource management

In response to the rapidly changing oil and gas development in the Upper Green River Basin, the Wyoming DEQ is implementing multiple air resource management strategies:

Permitting and compliance

The Wyoming DEQ has a program to ensure that all oil and gas production units are permitted and that Best Available Control Technology (BACT) is utilized to control or eliminate emissions. To guide oil and gas producers through the New Source Review (NSR) permitting process, the Wyoming DEQ developed the *Oil & Gas Production Facilities Chapter 6, Section 2: Permitting Guidance*. To address the increased activity and emission levels within the Jonah and Pinedale Anticline gas fields, the emission control requirements and permitting process were revised, effective July 28, 2004, with the result that more emissions are being controlled earlier in the life of the well for single-well facilities, and controlled on startup of all wells at multiple-well or drill pad facilities (WYDEQ 2004). Operators within the Jonah and Pinedale Anticline gas fields also must comply with permits issued by the Wyoming DEQ for all well completions and re-completions, which emphasize the implementation of flareless completion technology. In addition, the Wyoming DEQ is evaluating the permitting of drill-rig engines.

Emissions inventory and modeling

The Wyoming DEQ has undertaken an extensive analysis and modeling study designed to obtain the best possible estimate of the cumulative NO_2 PSD increment consumption from sources impacting southwestern Wyoming. The analysis focuses on the Bridger and Fitzpatrick wilderness areas, which are federally designated Class I areas, along with the surrounding Class II areas. The preliminary results of the modeling analyses indicate that the allowable NO_2 Class I and Class II increment levels and the NO_2 ambient air quality standard are not threatened. The final results of the modeling analyses will be available in early 2006. The Wyoming DEQ will continue to update the emissions inventory and modeling to evaluate cumulative NO_2 incrementation on a periodic basis.

Monitoring

Wyoming historically has required significant air quality monitoring of industrial activity. The Wyoming DEQ is furthering this legacy by expanding monitoring statewide, including in the Upper Green River Basin, in collaboration with industry. Since the fall of 2004, industry and the Wyoming DEQ have funded monitoring stations established in the Jonah Field, near Boulder, near Daniel, and in Pinedale. Monitoring stations are also being planned near Wamsutter, South Pass, Murphy Ridge, and in the Wyoming Range. The monitors are being strategically placed to assess actual ambient air quality impacts and also will serve as reality checks for modeling assumptions.

The Wyoming DEQ is increasing staffing and funding to expand upon and implement multiple air resource management strategies. The additional staffing and funding have been requested for the 2006–2007 budget, in addition to long-term funding from industry to directly support monitoring and modeling. Increased staffing in the Upper Green River Basin is also occurring as a direct result of mitigation commitments by industry in records of decision for environmental assessments and environmental impact statements.

Air quality monitoring programs and budgets in the Bridger-Teton and Shoshone national forests

The southwest Wyoming gas development activity is directly upwind of the Wind River Range, which contains two Class I and one Class II wilderness areas (the Bridger and Fitzpatrick wilderness areas and Popo Agie Wilderness Area, respectively); about 2,000 lakes; sensitive wilderness and air quality values; and high levels of wilderness recreation use. The USFS is mandated by the Clean Air Act and the Wilderness Act to protect AQRVs, including visibility, in Class I wilderness areas. Air quality monitoring within the Bridger-Teton and Shoshone national forests' Class I areas has been ongoing since the early 1980s. The current program consists of the following:

- **National Atmospheric Deposition Program (NADP):** Monitoring at Gypsum Creek

(Bridger-Teton National Forest) and South Pass (Shoshone National Forest).

- **Interagency Monitoring for Protected Visual Environments (IMPROVE):** An aerosol monitor and an optical monitor (transmissometer) located near Pinedale (above Fremont Lake) and at Dead Indian Pass northwest of Cody.
- **Long-term lakes:** Benchmark monitoring at five "long-term" lakes (Hobbs, Black Joe, Deep, Ross and Lower Saddlebag) in the Bridger, Fitzpatrick, and Popo Agie wilderness areas in the Wind River Range, sampled three times a year, and at another lake very sensitive to atmospheric deposition, Upper Frozen Lake, sampled once a year. Lake sampling protocols measure water chemistry, plankton, macroinvertebrates, and several physical parameters.
- **Bulk deposition:** Two bulk deposition collectors that collect snow, rain, and dry deposition, co-located with two of the long-term lakes (Black Joe and Hobbs). These sites are analyzed for chemical parameters.

The deposition monitoring data for the Wind River Range NADP and bulk deposition sites indicate that sulfates are decreasing while nitrates are increasing. This is a common trend across the western U.S., which makes it complicated to try to relate the nitrate increases directly to accelerated energy development activities in southwest Wyoming. The Wind River Range lake chemistry data indicate a decreasing trend of acid neutralizing capacity in some of the long-term lakes (i.e., lakes are becoming more acidic). Some long-term lakes are storing more nitrates, which may lead to eutrophic conditions (Baron et al. 2001). A rigorous analysis of the lake data is needed to determine the significance of these trends.

Prescribed-fire and wildfire smoke

Wildfire smoke is the most dramatic air quality impact, and prescribed fire is the predominant emission-producing management activity practiced by the USFS and NPS in the GYA. Emissions from fire (wildland and prescribed) are an important episodic contributor to visibility-impairing aerosols, including organic carbon, elemental carbon, and particulate matter. Wildfire impacts are increasingly difficult to manage due to excessive fuel loads, history of fire exclusion, and climate change (drought and increasing temperatures). Prescribed fire and fuel treatment projects include broadcast burns (area burns designed to reduce fuels in a contiguous area over a landscape) and pile burns (discrete piles of slash from timber harvest and/or thinning from fuel treatment projects). Prescribed burns are designed to reduce the size, frequency, and intensity of wildland fires and improve fire control, increase predictability of fire effects, and allow for smoke emissions management.

The SIS (smoke impact spreadsheet) model (Air Sciences 2003) was used to estimate smoke particulate emissions ($PM_{2.5}$) in the GYA. The SIS model uses the FOFEM5 fire effects model (Reinhardt 2003), the CONSUME fuel consumption and particulate emission generation model, and the CALPUFF dispersion model to estimate smoke emissions. Average spring and fall broadcast- and pile-burned acres and $PM_{2.5}$ smoke emissions were tabulated by GYA unit according to Society of American Foresters fuel code and vegetation type for 2002–2004. In addition, 10-year (2005–2014) estimates of broadcast- and pile-burned acres and $PM_{2.5}$ smoke emissions by GYA unit according to vegetation type and wildfire acres burned (2002–2004) were also modeled for smoke emissions (Table 2).

The Caribou-Targhee, Bridger-Teton, and Shoshone national forests had the largest numbers of acres of prescribed fires in 2002–2004, due mainly to large number of sagebrush-treatment acres. Estimated treatments for 2005–2014 include the Gallatin National Forest among the four largest prescribed-fire treatment programs in the GYA. All GYA units plan to increase prescribed fire treatment acreages and prescribed fire smoke emissions during the next 10 years.

Estimated smoke emissions ($PM_{2.5}$) are roughly proportional to prescribed burn acres (Figures 1 and 2). Per-acre smoke emissions on the Bridger-Teton National Forest were less for 2002–2004, and estimated to be less for 2005–2014 due to a high percentage of sagebrush in the prescribed fire treatment area, which produces fewer per-acre emissions than conifers (e.g., Douglas-fir, lodgepole pine, and spruce-fir). All GYA units would increase prescribed fire smoke emissions ($PM_{2.5}$) during the next 10 years. The highest estimated emissions would be for the Shoshone National Forest, where an average of 1,000 acres per year each of Douglas-fir and lodgepole pine are anticipated to be burned during the next decade. Over the entire GYA, yearly average prescribed fire emissions are anticipated to increase by about 58% during the next 10 years.

The number of acres burned and the amount of smoke emissions ($PM_{2.5}$) produced by wildfire are much larger than the numbers of acres burned and the amount of smoke emissions produced by prescribed fire in all GYA units. On a per-acre basis, wildfire emissions produce more smoke than prescribed fire due to increased combustion from more favorable burning conditions (fuel moisture and meteorology). During 2000–2004, wildfire acreage exceeded prescribed fire acreage by five times and wildfire smoke emissions ($PM_{2.5}$) exceeded prescribed fire emissions by 24 times (Figure 3).

As prescribed fire treatment programs increase in the GYA, the differences between wildfire and prescribed fire smoke would be expected to decrease, but wildfire smoke will still be dominant in total smoke emissions. Total smoke emissions will de-

Figure 1. Average and Estimated Broadcast- and Pile-burned Acres

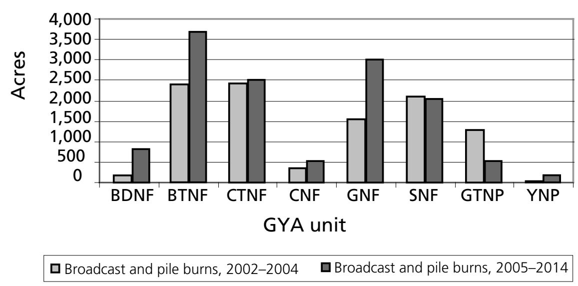

Figure 2. Average and Estimated $PM_{2.5}$ Tons/Yr from Broadcast and Pile Burns

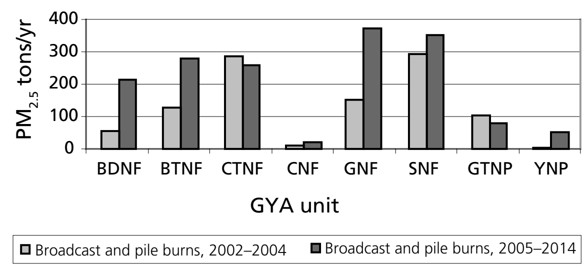

Table 2. Prescribed burn and wildfire acres and smoke emissions ($PM_{2.5}$) by GYA unit.

Unit	Average broadcast- and pile-burned acres, 2002–2004	Estimated broadcast- and pile-burned acres, 2005–2014	Average $PM_{2.5}$ tons/yr from broadcast and pile burns, 2002–2004	Estimated $PM_{2.5}$ tons/yr from broadcast and pile burns, 2005–2014	Average wildfire acres burned, 2002–2004	Average wildfire $PM_{2.5}$ tons/yr, 2002–2004
Beaverhead-Deerlodge NF (Madison Ranger District)	184	830	54	215	183	88
Bridger-Teton NF	2,380	3,670	129	279	11,945	5,782
Caribou-Targhee NF	2,416	2,503	287	260	2,672	1,293
Custer NF (Beartooth Ranger District)	364	514	9.4	20	2,091	1,012
Gallatin NF	1,546	3,000	153	374	11,359	5,498
Shoshone NF	2,093	2,040	294	351	9,383	4,541
Grand Teton NP	1,294	530	103	81	2,471	1,196
Yellowstone NP	27	161	2.6	53	11,397	5,516
Total GYA	**10,304**	**13,248**	**1,032**	**1,633**	**51,501**	**24,926**

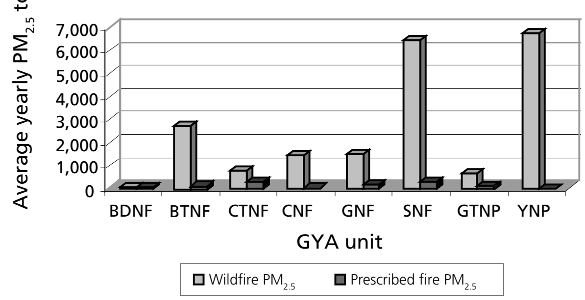

Figure 3. Wildfire and Prescribed Fire $PM_{2.5}$ for 2000–2004

pend largely on wildfire acreage, which is managed primarily through fire suppression. Wildfire smoke is considered to be a temporary natural source by the EPA and the DEQs of Montana, Idaho, and Wyoming, and is therefore not directly regulated. Prescribed fire smoke, however, is subject to NAAQS, and is managed to minimize smoke encroachment on sensitive areas (e.g., communities, Class I areas, high-use recreation areas, and scenic vistas) during sensitive periods. In the GYA, smoke dispersion is generally quite robust, with strong ridgetop winds generally blowing west or southwest. The most sensitive areas are communities in valley locations such as Lander, Dubois, and Jackson, Wyoming, and Red Lodge, Big Sky, and West Yellowstone, Montana, which are downwind of forested areas subject to wildfires and prescribed burning. During low dispersion times such as night and morning, smoke can concentrate and elevate $PM_{2.5}$ levels to nuisance concentrations, but generally not in excess of the 24-hour $PM_{2.5}$ standard of 65 $\mu eq/M^3$. All of the highest smoke concentrations in the GYA in the last two decades have been due to wildfires—many from regional fires west of the GYA. The southern part of the GYA, particularly the Bridger-Teton and Caribou-Targhee national forests and Grand Teton National Park (GRTE), is subject to smoke from agricultural burning in the Snake River valley. These impacts are cumulative with smoke emissions in the GYA. NEPA analysis for prescribed burning projects considers the sensitivity of smoke impacts, and when appropriate, the use of mitigation measures such as per-day burn acreage limitations, burning during periods of good wind dispersion, and non-burning alternatives to minimize conflicts. A key factor in prescribed fire implementation is coordination with the DEQs in Montana, Idaho, and Wyoming, which have regulatory authority over smoke emissions and public health.

The Montana/Idaho State Airshed Group's Smoke Monitoring Unit (SMU) consists of the USFS, the states of Montana and Idaho, the BLM, the NPS, and private burners. The purpose of the group is to manage and limit the impacts of smoke generated from prescribed burning. Accumulation of smoke from controlled burning is managed through monitoring of weather conditions and formal coordination. Members submit a list of planned burns to the SMU in Missoula, Montana. For each planned burn, information is provided describing the type of burn to be conducted, the number of acres, and the location and elevation at each site. Burns are reported by airshed—geographical areas with similar topography and weather patterns. The program coordinator and a meteorologist provide timely restriction messages for airsheds with planned burning. The Missoula SMU issues daily decisions that can restrict burning when atmospheric conditions are not conducive to good smoke dispersion. Restrictions may be directed by airshed, elevation, or by special impact zones around populated areas. The SMU announces burning restrictions via 17 airshed coordinators located throughout Idaho and Montana. The operations of the Montana/Idaho State Airshed Group are officially recognized as BACT by the Montana DEQ. The Montana/Idaho State Airshed Group Operating Guide can be found at <www.smokemu.org/>.

In 2004, the State of Wyoming revised Chapter 10 of the Wyoming Air Quality Standards and Regulations and developed a new Section 4, "Smoke Management Requirements." The new Section 4 regulates large-scale vegetative burning—specifically, vegetative burns in excess of 0.25 tons of PM_{10} emissions per day—for the management of air quality emissions and smoke impacts on public health and visibility. Section 4 succinctly lists the specific requirements of burners under a range of circumstances. The requirements of Section 4 are effective for planned burn projects and unplanned fire events occurring on or after January 1, 2005.

In support of Chapter 10, Section 4, the Wyoming DEQ's Air Quality Division (WDEQ-AQD) developed the Wyoming Smoke Management Program Guidance Document to assist burners with implementation of the regulations. The guidance document contains a review and explanation of the regulation's requirements, and is structured to include comprehensive resource material into two major sections: Wyoming Smoke Management

Program and Forms and Instructions.

A copy of Chapter 10 is posted in the Standards and Regulations portion of the WDEQ-AQD website. The entire document, along with a quick reference version, is posted in the Open Burning and Smoke Management portion of the WDEQ-AQD website, at <http://deq.state.wy.us/aqd/smokemanagement.asp>.

Snowmobile emissions detected in Yellowstone snowpacks, 1996–2004

Seasonal snowpacks accumulate throughout the winter in the Rocky Mountains without significant melt, storing airborne pollutants deposited during snowfall until snowmelt begins. In cooperation with the NPS and the USFS, the U.S. Geological Survey (USGS) has been collecting seasonal snowpack samples each spring since 1993, in a network of 50 regular sampling locations throughout the Rocky Mountain region. Nineteen snowpack sampling locations are located in the GYA. Seasonal snowpack samples were analyzed for concentrations of major ions to establish background and elevated concentrations representative of the region (Turk et al. 2001; Mast et al. 2001). Within this regional network, the USGS also investigated local effects of the acidifying ions ammonium and sulfate produced by snowmobile emissions on snowpack chemistry at Yellowstone National Park during 1996, and in 1998–2004. Results of snowpack sampling at locations with variable snowmobile usage annually showed clear patterns linking snowpack chemistry to snowmobile traffic.

Concentrations of ammonium and sulfate measured in snow samples taken directly from packed snowmobile routes in Yellowstone were substantially (up to three times) larger than concentrations of ammonium and sulfate measured in off-road snowpacks at least 30 meters away from snowmobile traffic. The relationship between concentrations of these ions and volumes of snowmobile traffic was reported by the USGS in earlier studies of the 1996 and 1998 snowpacks (Ingersoll et al. 1997; Ingersoll 1999). During these two years, concentrations of ammonium and sulfate and numbers of snowmobiles operating were highest near Old Faithful and the West Entrance. Concentrations of the two ions were lowest near areas with the least snowmobile usage: Lewis Lake Divide, the South Entrance, and Sylvan Lake. Similar patterns in concentrations of ammonium and sulfate were measured in snowpacks in 1999, 2000, and 2001, using the same protocols. Thin snowcover and deteriorating snow conditions prevented sampling of the snow-packed roadway at the West Entrance during the drier years of 2000 and 2001, so alternate locations were chosen at a low- and at a high-traffic site: the South Entrance and the West Parking Lot at Old Faithful, respectively. In all cases observed from 1996 to 2002, concentrations of ammonium and sulfate in snow-packed roadways increased with proximity to snowmobile usage at the high-traffic locations of West Yellowstone and Old Faithful. At these locations, off-road snowpack concentrations typically ranged from 5.1 to 14.0 microequivalents per liter (μeq/L) for ammonium and 3.5 to 7.6 μeq/L for sulfate. In-road sample concentrations at these sites ranged from 7.2 to 34.3 μeq/L for ammonium and 2.1 to 28.8 μeq/L for sulfate.

Decreases in concentrations of ammonium and sulfate began in 2002, and continued through 2004. Snow sample concentrations from off-road and in-road sites for the winters of 2003, and especially 2004, showed smaller differences and were considerably lower than in previous years. All ammonium and sulfate concentrations for samples from the paired off-road and in-road sites at West Yellowstone and Old Faithful in 2004 were less than 10 μeq/L. The decreases in concentrations of ammonium and sulfate in 2003 and 2004 coincided with expanded use of four-stroke snowmobiles, limited use of two-stroke snowmobiles, and overall reductions in snowmobile numbers.

Snowmobile use, management, air monitoring, and clean technology trends in Yellowstone and Grand Teton national parks

The burgeoning popularity of snowmachines in and around the GYA in the late 1980s and early 1990s led to concerns about air pollution, noise, wildlife harassment, and reduction in the quality of winter visitor experience. Snowmobile use in YNP generated the most widely publicized controversy. By the year 2000, visitors were making about 75,000 snowmobile trips and 1,300 snowcoach trips into the park during a 90-day winter season. More than 60% of those visitors entered the park through the West Entrance, from West Yellowstone. On peak days, more than 1,000 two-stroke snowmobiles used the West Entrance, where winter inversions often confine dense, cold, stable air that concentrates air pollution.

The traditional two-cycle engine snowmobiles being used released high hydrocarbon (HC), CO, and PM emissions, as well as a variety of gases classified as toxic air pollutants, including benzene, 1,2-

butadiene, formaldehyde, and acetaldehyde. In addition, 20–33% of the snowmobiles' fuel was emitted as unburned aerosols.

Monitoring by the Montana DEQ documented that the air quality at the West Entrance was, at times, very close to being in violation of the eight-hour NAAQS for CO, usually on calm winter days when there was little air dispersion.

The controversy about snowmobile emissions and access to U.S. national parks and other public lands has prompted studies, rulings, lawsuits, and technological innovations aimed at producing cleaner, quieter snowmobiles. One of the most significant technological changes has been the development of commercially available four-stroke snowmobiles, especially those that meet the NPS's BACT requirements. Laboratory testing of snowmobile emissions concluded that commercially available BACT four-stroke snowmobiles are significantly cleaner than two-stroke snowmobiles. Compared to previously tested two-strokes, these four-stroke snowmobiles emit 95–98% fewer HC, 90–96% less PM, 85% less CO, and 90% fewer toxic HC such as 1,3-butadiene, benzene, formadehyde, and acetaldehyde than two-stroke engines. The four-stroke engines, however, emit 7–12 times more NOx (Lela and White 2002).

To address historical concerns of snowmobile use and types, including air quality, the NPS has adopted a multifaceted approach for Yellowstone and Grand Teton national parks that includes limiting snowmobile numbers, requiring that snowmobilers use commercial guides, and requiring that snowmobiles be BACT, which are the cleanest and quietest four-stroke snowmobiles available. The commercial guide requirement helps ensure that the snowmobiles meet the BACT requirements, comply with speed limits, and stay on designated roads. Reduction in overall snowmobile numbers also has resulted in fewer emissions and better compliance with winter air quality objectives.

In November 2004, the NPS approved temporary winter use plans for Yellowstone and Grand Teton national parks and the John D. Rockefeller, Jr., Memorial Parkway (JODR). This decision allows 720 commercially guided recreational snowmobiles per day in YNP. In GRTE and JODR, 140 snowmobiles per day are allowed. With minor exceptions, all snowmobiles are required to meet NPS BACT requirements. The plan will be in effect for three winters, allowing snowmobile and snowcoach use through the winter of 2006–2007.

In addition to switching to BACT snowmobiles, YNP is using ethanol-blend fuels and low-emission lubricating oils to further reduce emissions. Ethanol-blend and biodegradable low-emission lubricating oils in two-stroke engines reduce CO emissions by 7–11%, PM by 25–70%, and HC by 16–38% (Montana DEQ 2005). Use of 10%-ethanol blend requires no engine modifications or adjustments; it is now the only unleaded "regular" fuel sold at the YNP gas stations. Snowmobile and snowcoach rental operators in and around YNP have taken similar steps to protect air and water quality, using 10%-ethanol-blend fuel and synthetic lubricating oils in their machines.

Winter season gasoline sales in the park dropped 82% from 2001 to 2005 (Guengerich 2005). Typical four-cycle engine snowmobiles get significantly better mileage (25–30 mpg) than typical two-cycle snowmobiles, at 9–13 mpg (H. Haines, pers. comm.). Thus, snowmobilers can now complete their trips in one tank of gas and typically no longer have to refuel in YNP.

Air quality monitoring began at YNP's West Entrance in the winter of 1998–1999, and at the Old Faithful development area in the winter of 2002–2003. A significant decrease in air pollutant concentrations for CO and $PM_{2.5}$ has been measured at both sites. A 60% decrease in CO and a 40% decrease in $PM_{2.5}$ were recorded at the West Entrance in 2003–2004, compared with the previous winter. A 23% decrease of CO and a 60% decrease in $PM_{2.5}$ were recorded at Old Faithful for the same time period. This closely tracks with a 56% decrease in the number of snowmobiles entering the West Entrance and a 53% decrease in the snowmobiles counted at Old Faithful (Ray 2005). Carbon monoxide has been decreasing at the West Entrance since 1998. Mean monthly CO levels at the West Entrance show an annual cycle, with the highest concentrations in winter and summer and lowest in spring and fall. Winter CO levels are now similar to those of July and August. This represents a substantial change from 1998–2002, when winter CO levels were much higher than summer levels.

Monitoring in winter 2004–2005 (Bishop et al. 2005) revealed a substantial finding: snowcoaches have higher emissions than individual snowmobiles, and the increase in snowcoach use is offsetting some of the snowmobile emission reductions. On a per-passenger basis, snowcoach emissions nearly equal four-stroke snowmobile emissions. Bishop (et al. 2005) measured emission rates and reported that older snowcoaches, such as the fuel-controlled carburetor Bombardier and fuel-injected, gasoline-van

Xanterra snowcoaches, had high CO and HC emissions. Newer snowcoaches, such as the fuel-injected MPI Bombardier used by Yellowstone AlpenGuides, and the NPS diesel van, had CO and HC emissions that were only 1–2% of that of older snowcoaches. Bishop (2005) discouraged the use of vintage, fuel-controlled carburetor engines in snowcoaches. This could substantially reduce overall snowcoach emissions.

Summary of management implications and recommendations

Air quality in the GYA remains generally excellent, as the GYA is largely undeveloped and has limited emissions sources and predominantly robust dispersion. Emission sources on NPS and USFS lands in the GYA primarily consist of prescribed fire smoke, transportation and recreational sources, and management activity sources such as mining, road construction, and ski areas. These sources are indirectly managed by the NPS and USFS, and are usually not significant air quality issues, except for snowmobile emissions at concentrated winter use areas such as the West Entrance. The NPS has greatly reduced winter emissions related to park management with the use of "green" fuels and products, and by requiring four-stroke snowmobile engines in YNP and GRTE.

Wildfire emissions are the most significant emissions within and around the GYA, but are not controllable by management except indirectly, by fire suppression. During the last three years, prescribed fire emissions in the GYA have increased due to the Healthy Forests Initiative legislation; they are anticipated to continue to increase by about 58% over the next 10 years. Overall smoke emissions (wildfire and prescribed) are expected to remain about the same, but with the major variable of weather conditions. Because much of the GYA, like most of the American West, has an accumulation of fuels resulting from wildfire suppression, wildfire levels are expected to be high during dry summer periods for the next several decades.

The greatest threat to air quality in the GYA is from anthropogenic sources upwind and adjacent to national park and national forest boundaries. Urban and industrial air pollution, although moderate compared to that in much of the U.S., has a persistent impact, because many of these emissions occur year-round, including during winter inversion periods. These sources are managed primarily by the DEQs in Montana, Wyoming, and Idaho, with collaboration from the NPS, USFS, and BLM for major sources such as PSD. The largest cities around the GYA, such as Billings/Laurel and Bozeman, Montana; Cody, Lander, and Jackson, Wyoming; and Idaho Falls, Idaho, are substantial sources of multiple emissions.

Currently, the largest air quality concerns in the GYA come from gas field development in southwest Wyoming and emissions from energy-related industries. The southwest Wyoming gas fields, primarily on BLM lands, are expanding at a very high rate because this area provides a significant contribution to the U.S. energy supply. The Clean Air Act requires the NPS and USFS to identify, monitor, and protect AQRVs in adjacent Class I areas. Visibility, lake chemistry, and biota in the Bridger-Teton Wilderness Area are being subjected to increasing levels of air pollution impacts from the gas field development. The Fitzpatrick and Popo Agie wilderness areas are also affected. Grand Teton National Park personnel would like to establish NADP/NTN (National Atmospheric Deposition Program/National Trends Nework), CASTNet (Clean Air Standards and Trends Network), and IMPROVE monitoring sites in Grand Teton National Park for at least five years, to compare with the network sites in Yellowstone National Park and determine if it is appropriate to augment the YNP air quality monitoring sites with more specific monitoring information from GRTE.

Compliance with NAAQS and protection of AQRVs will require continued close coordination between the NPS, USFS, BLM, and the DEQs in Wyoming, Montana, and Idaho. The GYACAP has been a useful forum to facilitate coordination between the GYA air quality management agencies.

Recommendations

1. Comply with NAAQS, PSD increments, and AQRV thresholds.
2. Cooperate with the Wyoming DEQ, BLM, and energy companies to manage southwest Wyoming oil and gas energy impacts.
3. Continue the system of air quality monitoring throughout the GYA. Air-quality-related-value monitoring of lakes, deposition, and visibility in the Wind River Range is critical.
4. Continue to encourage cleaner snowmobiles and snowcoaches, and to manage their winter use impacts.
5. Aggressively pursue fuel reduction projects and disclose smoke impacts and NAAQS compliance in NEPA documents.

6. Continue GYACAP annual meetings, coordination, and information exchange.

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