**TABLE OF EXHIBITS – Project No. 2013-013-SIP-NR**

**Comments on Texas 2014 Five-Year Regional Haze SIP Revision**

| | |
|---|---|
| Exhibit 1 | National Park Service, Big Bend National Park General Management Plan (2004) (Excerpts) |
| Exhibit 2 | National Park Service, Guadalupe Mountains National Park Draft General Management Plan (2008) (Excerpts) |
| Exhibit 3 | National Park Service, Understanding Haze in Big Bend Nat'l Park |
| Exhibit 4 | EPA, Health – Nitrogen Dioxide, Sulfur Dioxide, Particulate Matter |
| Exhibit 5 | EPA, Fact Sheet - Final Amendments to the RHR and BART Guidelines |
| Exhibit 6 | Ceres, New Jobs – Cleaner Air: Employment Effects Under Planned Changes to the EPA's Air Pollution Rules (2011) |
| Exhibit 7 | Daniel J. Stynes, Mich. State Univ., Economic Benefits to Local Communities from National Park Visitation and Payroll, 2010 (2011) |
| Exhibit 8 | National Park Service, National Park System – Summary: 1990 to 2008 |
| Exhibit 9 | Jared Hardner & Bruce McKenney, Hardner & Gullison, The U.S. National Park System, An Economic Asset at Risk (2006) |
| Exhibit 10 | Headwater Economics, Nat'l Park Serv. Units: Economic Impacts of Visitation & Expenditures |
| Exhibit 11 | Abt Associates Inc., Out of Sight: The Science and Economics of Visibility Impairment (2000) |
| Exhibit 12 | EPA, Effects of Acid Rain |
| Exhibit 13 | William D. Bowman et al., Nitrogen critical loads for alpine vegetation and soils in Rocky Mountain National Park, 103 Journal of Envtl. Mgmt. 165–71 (2012) |
| Exhibit 14 | National Park Service, Nitrogen Deposition: Issues and Effects in Rocky Mountain National Park (2005) |
| Exhibit 15 | EPA, Ground-level Ozone – Ecosystem Effects |
| Exhibit 16 | National Park Service Comments on TCEQ's 5-Year Progress Report (Aug. 20, 2013) |
| Exhibit 17 | National Park Service Comments on Texas Regional Haze SIP (Jan. 11, 2008) |
| Exhibit 18 | EPA, Technical Support Document for Demonstration of the Transport Rule as a BART Alternative (2011) |
| Exhibit 19 | Dr. Tammy M. Thompson, Air Quality Modeling Analysis of the Impacts of Emissions from Seven Texas-Located Point Source Facilities on Visibility at Four Class I Areas in Texas, Arkansas, and Oklahoma (Mar. 21, 2012) |
| Exhibit 20 | Bentek Energy, Texas Observer |
| Exhibit 21 | Bentek: Eagle Ford Crude Oil Production Expected to Grow, Bloomberg, Apr. 18, 2011 |
| Exhibit 22 | Al Armendariz, Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements (2009) |

# EXHIBIT 1

United States Department of the Interior
National Park Service

Big Bend National Park
Texas

# Big Bend National Park

## Final General Management Plan/ Environmental Impact Statement

# AFFECTED ENVIRONMENT

Phil Nichols

Bill Chambers

B. Dann

T. Smith

# NATURAL RESOURCES

## SETTING

Big Bend National Park comprises 801,000 acres in southern Brewster County in southwestern Texas in the northernmost portion of the Chihuahuan Desert. The Chihuahuan is the largest of North America's four deserts. The name Big Bend is applied to the area that is bordered on three sides by the Rio Grande. The park is only a part of this area. The elevation ranges from about 1,700 feet at the point where the Rio Grande leaves the park to 7,825 feet on top of Emory Peak. Big Bend National Park is known for its scenic beauty, which ranges from stark seemingly barren wastelands to majestic forested mountains to gigantic canyons. Visitors also come to observe the flora and fauna, much of which is typical of the Chihuahuan Desert.

Although water resources dot the landscape and flash floods occur after heavy rains, the Rio Grande provides the park's most prominent source of water (http://www.nps.gov/bibe/riograng.htm 8/20/01).

The Rio Grande defines the park's southern boundary for 118 miles. A 196-mile portion of the Rio Grande, designated as part of the Wild and Scenic River system, is administered by the park. Only 69 miles of the Wild and Scenic River are within the park boundary. The remaining 127 miles are downstream of the park.

Big Bend National Park is a UNESCO-designated Man and the Biosphere (MAB) Reserve representing the Chihuahuan Desert.

## SOILS

The following discussion describes the soils in the areas that would be affected by implementing actions proposed in the alternatives of this general management plan. All of the information regarding soil resources came from the *Soil Survey of Big Bend National Park*, *Part of Brewster County, Texas* (U.S. Soil Conservation Service 1985).

The soils in Big Bend National Park occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. These soils are delineated on soil survey maps and depicted as soil map units. For each soil map unit the soil survey provides specific information regarding a wide variety of uses and management issues.

Topsoil in the park is virtually nonexistent. Instead, subsoils, containing higher concentrations of calcium carbonate and sodium, are exposed. This is an important factor in efforts to revegetate disturbed areas, especially in the extremely arid conditions at the park.

In the following descriptions of limitations of soils at specific locations in the park, only those limitations that apply to actions in one or more alternatives are discussed. For example, because no campground is considered in any alternative for Panther Junction, no soil limitations for campgrounds are described for Panther Junction. However, because buildings are proposed for Panther Junction in one or more alternatives, limitations for building foundations are described.

### Chisos Basin

According to the soil survey, one soil map unit occurs within the developed area: LMF Liv-Mainstay-Rock Outcrop Complex, steep.

The Liv-Mainstay-Rock Outcrop Complex, steep, covers all of the developed area except the route of the road to the Basin; it consists of shallow and deep, very cobbly, and very gravelly soils with areas of exposed rock outcrop on igneous hills and mountains. Slopes are steep, generally ranging from 20% to 45%, although they can range from 8% to vertical rock walls. Elevation of this soil ranges from 5,000 to about 6,200 feet. Stones and large boulders that have fallen from igneous rock ledges are scattered across the surface of these areas. The soils are well drained. Surface runoff is rapid. Water

# EXHIBIT 2

DRAFT GENERAL MANAGEMENT PLAN /
ENVIRONMENTAL IMPACT STATEMENT

National Park Service
United States Department of the Interior

# GUADALUPE MOUNTAINS NATIONAL PARK
## Texas

## CHAPTER 3:
# AFFECTED ENVIRONMENT

# INTRODUCTION

This chapter describes the existing environment of Guadalupe Mountains National Park. The focus is on the park resources, visitor uses and experiences, socioeconomic environment, and park operations and facilities that could be affected by implementation of the alternatives. These topics were selected based on federal laws and regulations, executive orders, NPS expertise, and concerns expressed by other agencies or members of the public during scoping for this management plan. The conditions described in this chapter establish the baseline for the evaluation of environmental consequences that is provided in Chapter 4.

The Council on Environmental Quality (1978) guidelines for implementing the National Environmental Policy Act require that the description of the affected environment must focus on describing the resources that might be affected by implementation of the alternatives. To enhance reader understanding, the first section in this chapter gives a broad overview of the park and its regional context. The following sections provide more detailed descriptions of the existing conditions of the park resources that could be affected by implementing one or more of the alternatives that were described in Chapter 2.

**Western escarpment**

## THE PARK AND ITS REGIONAL CONTEXT

Guadalupe Mountains National Park is in a remote, sparsely populated area of the southwestern United States. The park is in Culberson and Hudspeth Counties in west Texas, adjacent to the New Mexico state line.

The closest metropolitan areas are El Paso, Texas (population about 560,000), which is about 110 miles to the west, and Carlsbad, New Mexico (population about 25,000), which is about 55 miles northeast of the park. The nearest towns include the following:

- Queen, New Mexico, which is so small that it is not recognized by the U.S. Census Bureau, is 16 miles north of the park's Dog Canyon area.
- Dell City, Texas, is a small community of about 400 people serving an irrigated agricultural area about 20 miles west of the park boundary.
- Whites City, New Mexico, (population about 50) is 38 miles east of the park.
- Van Horn, Texas, the Culberson County seat with a population of about 2,000, primarily provides ranching and tourist services. It is approximately 60 miles south of the park

Administrative services are shared with Carlsbad Caverns National Park through an office in the city of Carlsbad, New Mexico.

Guadalupe Mountains National Park contains 86,416 acres. Most of the surrounding land is privately owned, although some land to the northwest, north, and northeast is owned by the U.S. government and managed by the U.S. Forest Service or Bureau of Land Management.

In the Dell City area, good underground aquifers allow farmers to irrigate several thousand acres and grow crops such as chilies and alfalfa. Elsewhere, the primary land use on private land outside the park is grazing. Because of the arid environment, extensive land areas are needed for grazing. As a result, ranches are large and ranch houses are widely spaced.

The Guadalupe Mountains are internationally significant because of their outstanding geologic, scientific, and scenic resources. Spectacular scenery is a major attraction for visitors. The Guadalupe escarpment rises steeply from the desert floor and is a major landmark along U.S. Highway 62/180. El Capitan, with its sheer, thousand-foot-high cliffs, is especially impressive. Guadalupe Peak, just north of El Capitan, is the highest point in Texas (8,749 feet). There are outstanding scenic vistas from Guadalupe Peak, Hunter Peak, and other locations in the remote high country.

The park contains important cultural resources, representing periods of human use by prehistoric peoples through the 19th century settlement and ranching operations. Several sites in the park are listed in or eligible for listing in the National Register of Historic Places.

Commercial airline services are available at El Paso and Carlsbad. Highway access to the park includes the following:

- Primary access is by U.S. Highway 62/180, which runs from El Paso to Carlsbad. This highway is a high-standard, two-lane road. About 4 miles of this highway are within the park boundary near Pine Springs.
- A paved road, New Mexico Highway 137, provides access to Dog Canyon from Queen, New Mexico to the north.

- The west side of the park can be accessed via Farm-to-Market Road 1576 from Dell City. A dirt road provides access to the Salt Basin Dunes area of the park.

Historically, a road crossed the southwest corner of the park from the William's Ranch to the old road to Dell City (the Gin Road). This 10-mile-long dirt road was only 8 to 10 feet wide and had an elevation gain of more than 1,370 feet. This road has not been used since the 1970s and is no longer passable by vehicles, with many deep arroyos cutting through the old roadbed. At one time, Hudspeth County constructed a bladed dirt road across private land from the west to connect to the western park boundary near this old road. It also has not been maintained and remains an old road scar on the landscape.

Power and telephone lines, high-pressure gas lines, and a transcontinental fiber-optic telephone cable generally parallel U.S. Highway 62/180 on the east and south sides of the park. To the west, power and telephone lines generally are outside the park, but traverse its southwest corner.

There is active oil and gas exploration on Bureau of Land Management and state of New Mexico lands northwest of the park, and on private lands in Texas to the south and southeast. Sulfur mining is occurring about 40 miles southeast of the park in Culberson County, Texas. Potash mines in the Carlsbad, New Mexico, area are still active, but production has declined in recent years. A small gypsum mine is less than 0.5 miles west of the park boundary near Dell City. A wind farm generates electricity in the Delaware Mountains several miles south of the park.

Outside the park, visitor facilities primarily are limited to rest stops with picnic tables at scenic locations. Except in Whites City, there is only one gasoline station between El Paso and Carlsbad. Whites City has a food store, fuel, restaurants, lodging, and camping. Non-local visitors to Guadalupe Mountains National Park who do not camp in the park obtain lodging at El Paso or Carlsbad, or, to a limited extent, Whites City, Van Horn, and Dell City.

Carlsbad Caverns National Park, a nationally known destination for travelers, is about 40 miles northeast of Guadalupe Mountains National Park. Other national park units in the region that are shown in the Guadalupe Mountains National Park Region map in the beginning of Chapter 1 include White Sands National Monument, Fort Davis National Historic Site, and Big Bend National Park.

## CLIMATE

Although the park's Chihuahuan Desert location shapes the local climate, other influences are apparent:

- The northern portions of the park in Dog Canyon are cooler and moister, reflecting a climate more like the Great Basin.
- Eastern portions of the park have Great Plains connections.
- The higher elevations can be classified as an isolated extension of the Rocky Mountains.

### Precipitation

Average annual precipitation is

- 17.72 inches in the high country, in the Bowl at 8,112 feet in elevation
- 17.40 inches on the east side of the park at Pine Springs at 5,440 feet in elevation
- 9.10 inches on the west side of the park at 3,867 feet in elevation

Winter fronts and summer convectional storms are primary sources of precipitation in the Guadalupe Mountains region. The higher elevations of the park tend to receive more winter precipitation, and the lower elevations receive more in the summer. Win-

ter fronts come from the west. Precipitation is generally gentle, widespread, and often of long duration. Winter storms usually begin around the end of October, and precipitation often falls as snow, with the relative amounts increasing both with elevation and latitude.

Summer storms, in late afternoon or evening rainfall, are fast moving, of short duration, and accompanied by high winds, thunder, and lightning. Rainfall from these cells is generally localized and heavy once the pattern sets up, with the initial development often bringing only dry lightning with virga (rainfall that evaporates before reaching the ground). Heavy downpours over sparsely vegetated desert uplands often cause flash flooding in downgradient canyons. These storms usually begin early in July, and the pattern persists until the end of September, when the interior of the southwest begins to cool down. The lightning associated with summer thunderstorms is the primary cause of natural fires that occur in the park.

### Temperatures

The average daily maximum for the warmest month (June) in the Pine Springs area at the eastern base of the mountain (5,500 feet above mean sea level) is about 88 degrees Fahrenheit, and temperatures above 90 degrees Fahrenheit are common. The average monthly temperature at Pine Springs for the coldest month (January) is 42 degrees Fahrenheit, and lows in the 20s are common. On average, the high country at an elevation greater than 8,000 feet above mean sea level is about 10 degrees Fahrenheit cooler than the Pine Springs area, and the western side of the park, at an elevation of about 3,600 feet above mean sea level, is about 10 degrees warmer.

### Winds

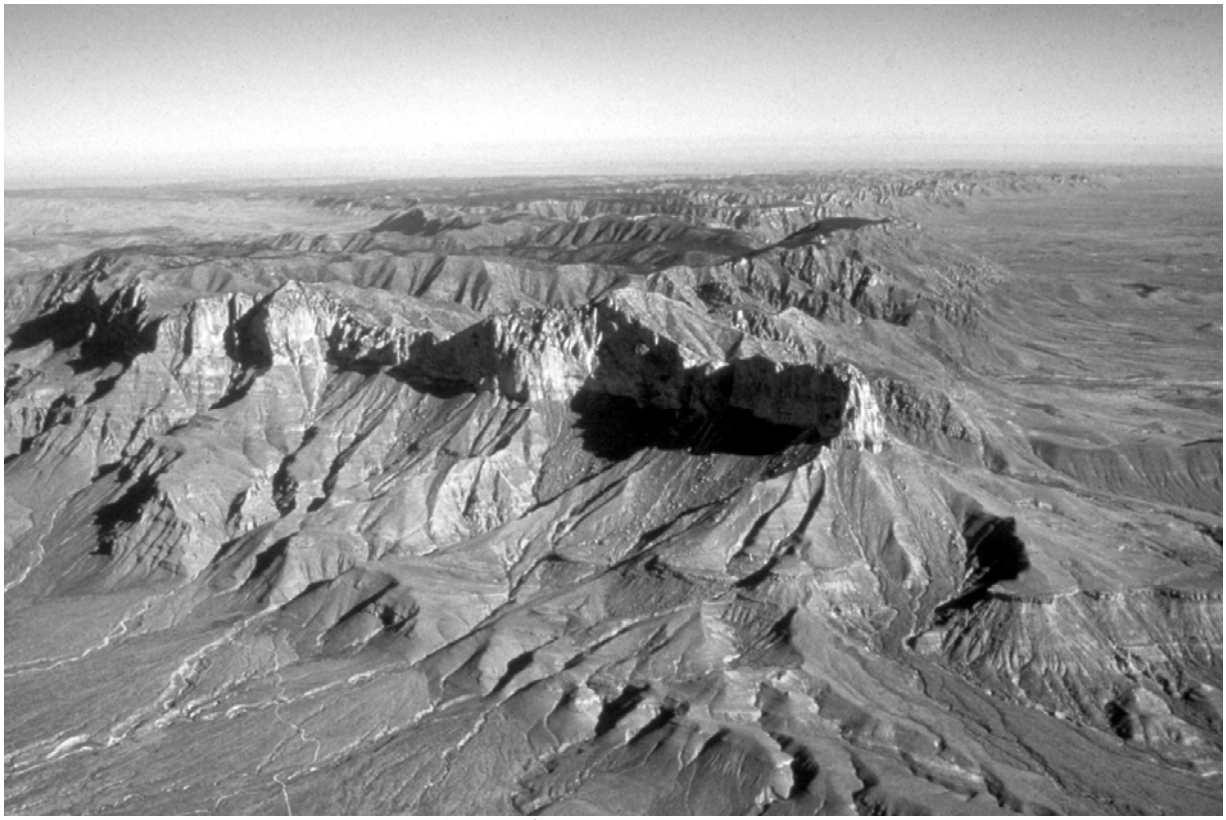
The Guadalupe Mountains, and especially Guadalupe Pass, are noted for high winds. The prevailing air movement is from the west and southwest. Local topography channels the wind into southwest-northeast directions, with southwest being the predominant direction. Strong winds often exceed 60 to 80 miles per hour, and can occur in excess of 100 miles per hour with the passage of cold fronts throughout the seasons from winter to early summer.

Topographic heating and cooling creates daytime upslope flow and nighttime downslope flow of air. By themselves, the thermal-related winds would not reach destructive velocities, but they may add 10 or 20 miles per hour to the velocity of wind from another source. This compounding effect makes the Guadalupes one of the windiest places in the nation.

## PHYSIOGRAPHY

Physiographically, the Guadalupe Mountains are characterized as part of the Sacramento Section of the Basin and Range Province (Fenneman 1931).

The lower elevations of Guadalupe Mountains National Park consist of mostly sparsely vegetated Chihuahuan Desert and rolling foothills. Within this setting, the uplifted Permian reef forms a huge, V-shaped escarpment. The uplift creates a “sky island” in the midst of the desert, in which rests the Bowl, an area of relict forests that provide mostly mixed conifer habitat.



**Aerial view of the Guadalupe Mountains**

El Capitan, on the southern end of the escarpment, is a prominent park landmark that is visible for more than 90 miles. The impressive escarpment extends northwest from El Capitan and contains other distinctive peaks, including the 8,749-foot-high Guadalupe Peak, the highest point in Texas. The next three highest peaks in Texas, all of which exceed 8,000 feet above sea level, also are in the park. The base of the western escarpment is 3,650 feet in elevation, some 5,100 feet lower than Guadalupe Peak.

The uplift of the Guadalupe Mountains probably occurred in Miocene times, resulting in a fault-block mountain mass that tilts slightly to the northeast and has as its westerly margin the sheer fault-scarp. Principal drainage of the mountain mass has been to the east, and has created deeply incised canyons where relict biota survive. To the west, the sheer, slightly dissected fault scarp forms the eastern boundary of a bolson, or valley having no outlet. The internal runoff from this area collects in a great, shallow, evaporation basin known as the Salt Flats.

The high country's major scenic and scientific features are not visible from the desert floor. The high country's features include the following:

- A distinctive area of relict forest includes ponderosa pine, southwestern white pine, Douglas-fir, and a small grove of aspen.
- The Bowl, which is in the center of the 45,000-acre high country forest, provides mixed-conifer habitat.
- McKittrick Canyon extends out of the high country and through the eastern escarpment. Its south arm possesses special scenic appeal and scientific importance because of its unique geology and biotic communities.

# EXHIBIT 3

National Park Service
U.S. Department of the Interior

Big Bend National Park

# Understanding Haze in Big Bend National Park
## Big Bend Regional Aerosol and Visibility Observational (BRAVO) Study

Big Bend National Park on a day with no haze

9-15-04

**BACKGROUND**

The scenic beauty of Big Bend National Park is often spoiled by haze that obscures its many vistas. In addition, Big Bend is one of the few national parks where haze has been increasing since the late 1980s. In 1999, the National Park Service and the U.S. Environmental Protection Agency carried out the Big Bend Regional Aerosol and Visibility Observational (BRAVO) study. Other participating agencies were the Texas Commission on Environmental Quality and the Electric Power Research Institute. The primary objective of BRAVO was to determine what causes the haze at Big Bend. The BRAVO study involved a four-month intensive monitoring period from July through October 1999, followed by a data analysis and modeling effort.

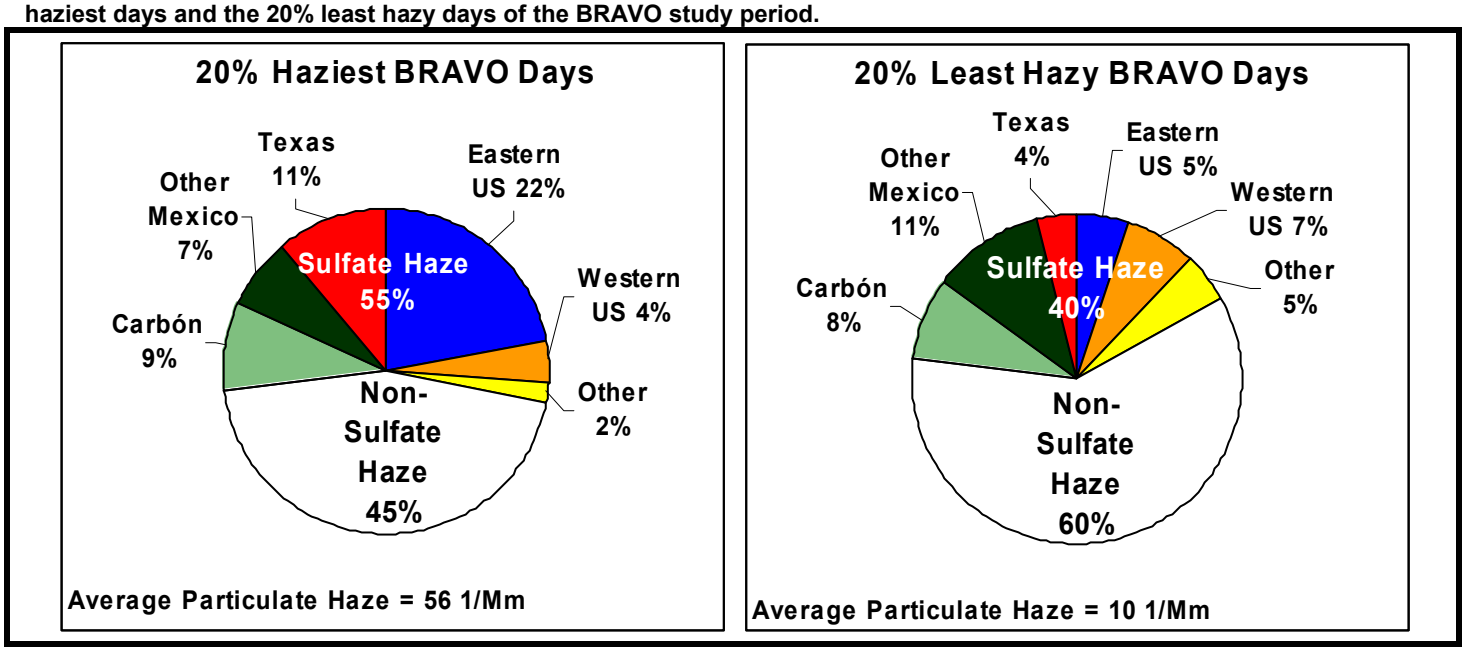
Haze is caused by scattering and absorption of light (light extinction) by suspended particles in the air. Particles can stay suspended in the atmosphere for many days and be transported for hundreds of miles. The composition of the particles varies depending on their human and natural sources. Sulfate particles are the single largest contributor to haze at Big Bend NP, accounting for about half of the haze on the average and on the haziest days. Sulfate particles form in the atmosphere from chemical reactions of sulfur dioxide gas. Sources of sulfur dioxide include coal-fired power plants, metal smelters, refineries, other industrial processes and volcanoes. Dust from the suspension of soil particles and carbonaceous material from forest fires also affect haze at Big Bend. The haze in Big Bend NP peaks in the spring months (April–June), when both sulfate and carbonaceous particles are the dominant contributors, and the late summer and early fall months (August–October) when sulfate particles alone dominate. The least hazy conditions occur during the winter months.

**Typical Haziest BRAVO day**

**Typical Least Hazy BRAVO day**

**Sulfates contribute approximately 50% of the light extinction at Big Bend National Park**

**Figure 1: Estimated contributions by particulate sulfate source regions to Big Bend particulate haze levels for the 20% haziest days and the 20% least hazy days of the BRAVO study period.**




## BRAVO Analyses

After the field measurement period, laboratory analyses of the air samples were completed. These analyses yielded the concentrations and chemical composition of the atmospheric particles and concentrations of unique tracer compounds that were released to assess transport. A number of data analysis methods were used to ascertain what source regions were contributing to the sulfate haze at Big Bend National Park. Some methods involved examining the relationships between different measured chemical components and unique tracer compounds, while others were based on numerical models of the meteorology, pollutant transport, and chemical reactions of the atmosphere. One aspect of the BRAVO study was the innovative way numerical atmospheric modeling was reconciled with the measured chemical compounds to give a more accurate assessment of the contributors to sulfate haze. Figure 1 summarizes the contributions on the haziest and least hazy days during the study.

## Next Steps for Improving Visibility at Big Bend National Park

In general, sulfur dioxide emission reductions should help reverse the trend for worsening visibility in the Big Bend region. This is particularly true of sources in Texas and the eastern U.S, given the significance of the contribution from those regions. Sulfur dioxide emission reductions from the western U.S and Northern Mexico would help maintain and improve the least hazy days.

There are current and pending federal regulations that should reduce sulfur dioxide emissions throughout the United States and make significant progress toward improving visibility in Big Bend National Park.

Although sources in Mexico are also shown to contribute to visibility impairment at Big Bend National Park, the U.S. government has no jurisdiction there. There have been partnerships between agencies in Mexico and the U.S. to address transport of pollution. Such a partnership might be of use in the Big Bend Region.

## BRAVO Findings

- On average, during the study period more than half of the sulfate at Big Bend National Park came from the U.S., in particular from the eastern U.S. and Texas.
- On average, Mexican sources contributed just over a third of the sulfate.
- The Carbon I and II power plants in Mexico contributed about one-fifth of the total sulfate measured at Big Bend National Park.
- Eastern US and eastern Texas sources were the largest contributors to peak particulate sulfate episodes during BRAVO.
- Airflow from eastern Texas and the eastern U.S. is most frequent during late summer and early fall months, when sulfate contributes most to haze.
- Mexico and the western U.S. were the largest contributors on the least hazy BRAVO days.
- The least hazy days were frequently associated with transport from the west.

**For More Information on the BRAVO study go to: www2.nature.nps.gov/air/studies/bravo/index.htm**

# EXHIBIT 4

http://www.epa.gov/air/nitrogenoxides/health.html

EPA United States Environmental Protection Agency

## Nitrogen Dioxide
# Health

Current scientific evidence links short-term $NO_2$ exposures, ranging from 30 minutes to 24 hours, with adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma.

Also, studies show a connection between breathing elevated short-term $NO_2$ concentrations, and increased visits to emergency departments and hospital admissions for respiratory issues, especially asthma.

$NO_2$ concentrations in vehicles and near roadways are appreciably higher than those measured at monitors in the current network. In fact, in-vehicle concentrations can be 2-3 times higher than measured at nearby area-wide monitors. Near-roadway (within about 50 meters) concentrations of $NO_2$ have been measured to be approximately 30 to 100% higher than concentrations away from roadways.

Individuals who spend time on or near major roadways can experience short-term $NO_2$ exposures considerably higher than measured by the current network. Approximately 16% of U.S housing units are located within 300 ft of a major highway, railroad, or airport (approximately 48 million people). This population likely includes a higher proportion of non-white and economically-disadvantaged people.

$NO_2$ exposure concentrations near roadways are of particular concern for susceptible individuals, including people with asthma asthmatics, children, and the elderly

The sum of nitric oxide (NO) and $NO_2$ is commonly called nitrogen oxides or NOx. Other oxides of nitrogen including nitrous acid and nitric acid are part of the nitrogen oxide family. While EPA's National Ambient Air Quality Standard (NAAQS) covers this entire family, $NO_2$ is the component of greatest interest and the indicator for the larger group of nitrogen oxides.

NOx react with ammonia, moisture, and other compounds to form small particles. These small particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death.

Ozone is formed when NOx and volatile organic compounds react in the presence of heat and sunlight. Children, the elderly, people with lung diseases such as asthma, and people who work or exercise outside are at risk for adverse effects from ozone. These include reduction in lung function and increased respiratory symptoms as well as respiratory-related emergency department visits, hospital admissions, and possibly premature deaths.

Emissions that lead to the formation of $NO_2$ generally also lead to the formation of other NOx. Emissions control measures leading to reductions in $NO_2$ can generally be expected to reduce population exposures to all gaseous NOx. This may have the important co-benefit of reducing the formation of ozone and fine particles both of which pose significant public health threats.

Last updated on Thursday, March 22, 2012

http://www.epa.gov/air/sulfurdioxide/health.html

EPA United States Environmental Protection Agency

## Sulfur Dioxide
# Health

Current scientific evidence links short-term exposures to $SO_2$, ranging from 5 minutes to 24 hours, with an array of adverse respiratory effects including bronchoconstriction and increased asthma symptoms. These effects are particularly important for asthmatics at elevated ventilation rates (e.g., while exercising or playing.)

Studies also show a connection between short-term exposure and increased visits to emergency departments and hospital admissions for respiratory illnesses, particularly in at-risk populations including children, the elderly, and asthmatics.

EPA's National Ambient Air Quality Standard for $SO_2$ is designed to protect against exposure to the entire group of sulfur oxides (SOx). $SO_2$ is the component of greatest concern and is used as the indicator for the larger group of gaseous sulfur oxides (SOx). Other gaseous sulfur oxides (e.g. SO3) are found in the atmosphere at concentrations much lower than $SO_2$.

Emissions that lead to high concentrations of $SO_2$ generally also lead to the formation of other SOx. Control measures that reduce $SO_2$ can generally be expected to reduce people's exposures to all gaseous SOx. This may have the important co-benefit of reducing the formation of fine sulfate particles, which pose significant public health threats.

SOx can react with other compounds in the atmosphere to form small particles. These particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death. EPA's NAAQS for particulate matter (PM) are designed to provide protection against these health effects.

Last updated on Thursday, July 12, 2012

http://www.epa.gov/air/particlepollution/health.html

## Particulate Matter (PM)
# Health

The size of particles is directly linked to their potential for causing health problems. Small particles less than10 micrometers in diameter pose the greatest problems, because they can get deep into your lungs, and some may even get into your bloodstream.

Exposure to such particles can affect both your lungs and your heart. Small particles of concern include "inhalable coarse particles" (such as those found near roadways and dusty industries), which are larger than 2.5 micrometers and smaller than 10 micrometers in diameter; and "fine particles" (such as those found in smoke and haze), which are 2.5 micrometers in diameter and smaller.

The Clean Air Act requires EPA to set air quality standards to protect both public health and the public welfare (e.g. visibility, crops and vegetation). Particle pollution affects both.

### Health Effects

Particle pollution - especially fine particles - contains microscopic solids or liquid droplets that are so small that they can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including:

- premature death in people with heart or lung disease,
- nonfatal heart attacks,
- irregular heartbeat,
- aggravated asthma,
- decreased lung function, and
- increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing.

People with heart or lung diseases, children and older adults are the most likely to be affected by particle pollution exposure. However, even if you are healthy, you may experience temporary symptoms from exposure to elevated levels of particle pollution. For more information about asthma, visit www.epa.gov/asthma.

### Environmental Effects

***Visibility impairment***
Fine particles ($PM_{2.5}$) are the main cause of reduced visibility (haze) in parts of the United States, including many of our treasured national parks and wilderness areas. For more information about visibility, visit www.epa.gov/visibility.

***Environmental damage***
Particles can be carried over long distances by wind and then settle on ground or water. The effects of this settling include: making lakes and streams acidic; changing the nutrient balance in coastal waters and large river basins; depleting the nutrients in soil; damaging sensitive forests and farm crops; and affecting the diversity of ecosystems. More information about the effects of particle pollution and acid rain.

***Aesthetic damage***
Particle pollution can stain and damage stone and other materials, including culturally important objects such as statues and monuments. More information about the effects of particle pollution and acid rain.

You will need Adobe Acrobat Reader to view the Adobe PDF files on this page. See EPA's PDF page for more information about getting and using the free Acrobat Reader.

**For more information on particle pollution, health and the environment, visit:**

Particle Pollution and Your Health (PDF) (2pp, 320k): Learn who is at risk from exposure to particle pollution, what health effects you may experience as a result of particle exposure, and simple measures you can take to reduce your risk.

How Smoke From Fires Can Affect Your Health: It's important to limit your exposure to smoke -- especially if you may be susceptible. This publication provides steps you can take to protect your health.

Integrated Science Assessment for Particulate Matter (December 2009): This comprehensive assessment of scientific data about the health and environmental effects of particulate matter is an important part of EPA's review of its particle pollution standards.

Last updated on Friday, June 15, 2012

# EXHIBIT 5

# FACT SHEET

# FINAL AMENDMENTS TO THE REGIONAL HAZE RULE AND GUIDELINES FOR BEST AVAILABLE RETROFIT TECHNOLOGY (BART) DETERMINATIONS

## ACTION

- On June 15, 2005, the Environmental Protection Agency (EPA) finalized amendments to the July 1999 regional haze rule. These amendments apply to the provisions of the regional haze rule that require emission controls known as best available retrofit technology, or BART, for industrial facilities emitting air pollutants that reduce visibility by causing or contributing to regional haze.

- The pollutants that reduce visibility include fine particulate matter (PM2.5), and compounds which contribute to PM2.5 formation, such as nitrogen oxides (NOx), sulfur dioxides (SO2), and under certain conditions volatile organic compounds, and ammonia.

- EPA evaluated three possible scenarios of actions the states may take to comply with this rule. Under the medium stringency scenario EPA estimates that BART controls will result in annual NOx reductions of about 600,000 tons. Emission reductions for SO2 will be approximately 400,000 tons annually.

- EPA's benefits analysis estimates that the amendments will lead to significant improvements in visibility in southeastern and southwestern parks. Under the medium stringency scenario this rule will provide approximately $240 million in improved visibility benefits each year. In 2015, the final rule also will provide substantial health benefits valued at $8.4 - $9.8 billion annually -- preventing 1,600 premature deaths, 2,200 non-fatal heart attacks, 960 hospital admissions, and over 1 million lost school and work days. The total annual cost will range from 1.4 – 1.5 billion dollars.

- The BART requirements of the regional haze rule apply to facilities built between 1962 and 1977 that have the potential to emit more than 250 tons a year of visibility-impairing pollution. Those facilities fall into 26 categories, including utility and industrial boilers, and large industrial plants such as pulp mills, refineries and smelters. Many of these facilities previously have not been previously been subject to federal pollution control requirements for these pollutants.

- Under the 1999 regional haze rule, states are required to set periodic goals for improving visibility in the 156 natural areas. As states work to reach these goals, they must develop regional haze implementation plans that contain enforceable measures and strategies for reducing visibility-impairing pollution. Today's amendments include guidelines, known as BART guidelines, for states to use in

determining which facilities must install controls and the type of controls the facilities must use.

- States must develop their implementation plans by December, 2007. States will identify the facilities that will have to reduce emissions under BART and then set BART emissions limits for those facilities.

- States must consider a number of factors when determining what facilities will be covered by BART including:

  - the cost of the controls;
  - the impact of controls on energy usage or any non-air quality environmental impacts;
  - the remaining useful life of the equipment to be controlled;
  - any existing pollution controls already in place; and
  - visibility improvement that would result from controlling the emissions.

- The guidelines also explain:

  - How to identify the plants and equipment for which a BART analysis is required;
  - The circumstances under which a source may or may not be exempt from a detailed BART review;
  - The procedures for reviewing available emission control methods, and procedures for summarizing and reporting the results of this review; and
  - The type of air quality analysis that is needed to inform the state's BART determination.
  - In a separate action EPA will propose additional revisions to the regional haze rule in the near future to address alternative emissions trading programs.

- On March 10, 2005, EPA issued the Clean Air Interstate Rule (CAIR), requiring reductions in emissions of SO2 and NOx from electricity generating units (EGUs) in 28 eastern States and the District of Columbia. When fully implemented, CAIR will reduce SO2 emissions in these states by over 70 percent and NOx emissions by over 60 percent from 2003 levels. The CAIR establishes an EPA-administered cap and trade program for EGUs in which States may participate as a means to meet these requirements. In the BART rule, EPA presents the results of an analysis showing that controls for EGUs subject to CAIR will result in more visibility improvement in natural areas than BART would have provided. Therefore, States which adopt the CAIR cap and trade program for SO2 and NOx are allowed to apply CAIR controls as a substitute for controls required under BART because our analysis concluded that CAIR controls are "better than BART" for EGUs in the states subject to CAIR.

- This rule will take effect 60 days after it is published in the *Federal Register*.

## BACKGROUND

- Regional haze is a national problem caused by multiple sources over a wide area. Visibility is affected by different sources at different times of the year and under different weather conditions. Some other significant contributors to visibility impairment include car and truck emissions, area sources (broadly distributed and numerous small sources), wildfires, agricultural fires, and wind blown dust.

- The same pollution that causes haze also poses health risks for some people with chronic respiratory diseases.

- To reduce haze, and to meet requirements of the Clean Air Act, EPA in April 1999 issued a regional haze rule aimed at protecting visibility in 156 federal areas. The rule seeks to reduce the visibility impairment caused by many sources over a wide area. EPA's previous visibility regulation, issued in 1980, addressed only local visibility impairment from local sources.

- Soon after the regional haze rule was finalized, several parties filed petitions to challenge the rule with the U.S. Court of Appeals for the D.C. Circuit.

- Because regional haze is a problem caused by multiple sources over a wide area, EPA's 1999 rule allowed states that were determining BART requirements to assess visibility impacts from multiple sources rather than on a source-by-source basis. In May 2002, the court ruled that aspects of EPA's specific approach to this issue were not consistent with the Clean Air Act.

- On April 15, 2004 EPA reproposed a rule in response to the May 2002 ruling by the U.S. Court of Appeals for the D.C. Circuit vacating parts of the BART provisions of the regional haze rule (*American Corn Growers et al. v. EPA*, 291 F. 3d 1 (D.C. cir. 2002)).

- EPA initially proposed BART guidelines on July 20, 2001, but did not finalize that proposal, in light of the 2002 Court ruling.

- The 2004 proposal provided a process by which states can consider an individual facility's contribution to regional haze when determining whether to require controls, and what the level of control should be.

- For large electric generating units, this rule recommends specific emissions limits for nitrogen oxides and sulfur dioxide.

## FOR MORE INFORMATION

- A copy of this notice and a copy of the Regional Haze rule is available at http://www.epa.gov/visibility

# EXHIBIT 6

# NEW JOBS — CLEANER AIR

# Employment Effects Under Planned Changes to the EPA's Air Pollution Rules

**February 2011**
*A Ceres Report*

Ceres

POLITICAL ECONOMY RESEARCH INSTITUTE
PERI
University of Massachusetts Amherst

**Authored by**
University of Massachusetts
Political Economy Research Institute
James Heintz
Heidi Garrett-Peltier
Ben Zipperer

**Ceres** is a national coalition of investors, environmental groups, and other public interest organizations working with companies to address sustainability challenges such as climate change and water scarcity. Ceres directs the Investor Network on Climate Risk, a group of 95 institutional investors and financial firms from the U.S. and Europe managing nearly $10 trillion in assets.

The **Political Economy Research Institute (PERI)** is an economic policy research organization affiliated with the University of Massachusetts, Amherst. PERI conducts academic research that is directly engaged with crucial economic policy issues. PERI has broad, and intersecting, areas of specialty: macroeconomics, financial markets and globalization; labor markets (especially low-wage work, both in the U.S. and globally); economic development (with a particular focus on Africa); the economics of peace; and environmental economics.

**Acknowledgments**

PERI would like to acknowledge the contributions of Ying Chen who worked as a research assistant on this project.

**Cover Photo Credits**

Smokestack with the American flag: PSNH
Workers in hard hats: PSEG

**For more information, contact:**

James Heintz
Associate Research Professor and Associate Director
Political Economy Research Institute
University of Massachusetts, Amherst
418 N. Pleasant St. Suite A
Amherst, MA 01002
jheintz@peri.umass.edu

# NEW JOBS—CLEANER AIR

## Employment Effects Under Planned Changes to the EPA's Air Pollution Rules

## Table of Contents


FOREWORD . . . . . ii

EXECUTIVE SUMMARY . . . . . 1

Key findings:. . . . . 2

I. INTRODUCTION. . . . . 4

II. EASTERN INTERCONNECTION EMPLOYMENT IMPACTS UNDER PLANNED EPA RULES . . . . . 10

Capital Improvements Spending on Pollution Controls and New Generation Capacity . . . . . 10

O&M Jobs . . . . . 12

III. STATE-LEVEL ANALYSIS OF EMPLOYMENT IMPACTS. . . . . 14

State-level Spending on Pollution Controls and New Generation. . . . . 14

State-level Estimates of O&M Jobs from Capital Improvements . . . . . 14

State-level Estimates of Job Reductions from Retirements. . . . . 17

CONCLUSION . . . . . 18

APPENDIX A . . . . . 19

APPENDIX B. . . . . 23

Methodology and Assumptions . . . . . 23

# FOREWORD

The U.S. electric power sector is changing and modernizing in response to societal and market forces. Power companies face a business imperative to meet increasing pressures for cleaner, more efficient energy that will safeguard public health and protect the world's climate.

These forces are already transforming the industry. Significant capital investment has been flowing in recent years to cleaner technologies such as renewable energy, energy efficiency and natural gas-fired generation. Investment to clean up and modernize the nation's existing fossil fuel generation fleet has already begun to contribute to a cleaner energy future.

New air pollution rules expected this year from the U.S. Environmental Protection Agency will further accelerate these trends. And – as this new Ceres report shows - they will have a major added benefit: significant job creation.

Meeting new standards that limit sulfur dioxide, nitrogen oxides, mercury and other pollutants will create, in the report's own words, "a wide array of skilled construction and professional jobs" – from the electricians, plumbers, laborers and engineers who will build and retrofit power plants all across the eastern U.S., to operation and maintenance (O&M) employees who will keep the modernized facilities running.

The report finds that investments driven by the EPA's two new air quality rules will create nearly 1.5 million jobs, or nearly 300,000 jobs a year on average over the next five years – and at a critical moment for a struggling economy. The end product will be an upgraded, cleaner American industry, along with good paying jobs and better health for the nation's most vulnerable citizens.

For this report, researchers at the University of Massachusetts' Political Economy Research Institute carefully gauged the job impacts of pending and proposed EPA rules, using independent models and conservative assumptions. Its findings are especially good news for the many states, such as Ohio, Michigan, Pennsylvania, Virginia and Missouri, that are most dependent on traditional fossil fuel energy and most worried about traditional industrial jobs losses.

America's status as one of history's great economic powerhouses has long depended on our willingness and ability to reinvest and innovate when changing times tell us it's time to retool. We've seen throughout our history that clean technology investments – whether to clean our rivers, improve our air quality or compete in the emerging low-carbon global economy – have long-term benefits that far outweigh the upfront costs.

Since 1970, investments to comply with the Clean Air Act have provided $4 to $8 in economic benefits for every $1 spent on compliance, according to the nonpartisan Office of Management and Budget. Since the passage of the Clean Air Act Amendments in 1990, U.S. average electricity rates (real) have remained flat even as electric utilities have invested hundreds of billions of dollars to cut their air pollution emissions. During the

same period, America's overall GDP increased by 60 percent in inflation-adjusted terms. The bottom line: clean air is a worthwhile investment.

Significant change is often unsettling, never without short-term costs and some dislocation. But failing to change, especially now, offers much grimmer prospects. We are entering – in fact have already entered – a great global industrial and economic realignment toward clean energy. The greatest benefits, for both today's families and future generations, will flow to those who anticipate these changes, and take proactive steps to respond.

For our electric power sector and the workers tied to it, this report outlines why this path makes sense.

Mindy S. Lubber
President of Ceres

THIS PAGE INTENTIONALLY LEFT BLANK

# EXECUTIVE SUMMARY

Clean air safeguards have benefitted the United States tremendously. Enacted in 1970, and amended in 1990, the Clean Air Act ("CAA") has delivered cleaner air, better public health, new jobs and an impressive return on investment—providing $4 to $8 in benefits for every $1 spent on compliance.[1]

History has proven that clean air and strong economic growth are mutually reinforcing. Since 1990, the CAA has reduced emissions of the most common air pollutants 41 percent while Gross Domestic Product increased 64 percent.[2] Clean air regulations have also spurred important technological innovations, such as catalytic converters, that helped make the United States a world leader in exporting environmental control technologies.

This study, prepared by the University of Massachusetts' Political Economy Research Institute (PERI), demonstrates how new air pollution rules proposed for the electric power sector by the Environmental Protection Agency ("EPA") will provide long-term economic benefits across much of the United States in the form of highly skilled, well paying jobs through infrastructure investment in the nation's generation fleet. Significantly, many of these jobs will be created over the next five years as the United States recovers from its severe economic downturn.

Focusing on 36 states[3] in the eastern half of the United States, this report evaluates the employment impacts of the electric sector's transformation to a cleaner, modern fleet through investment in pollution controls and new generation capacity and through retirement of older, less efficient generating facilities. In particular, we assess the impacts from two CAA regulations expected to be issued in 2011: the Clean Air Transport Rule ("Transport Rule") governing sulfur dioxide ($SO_2$) and nitrogen oxide (NOx) emissions from targeted states in the eastern half of the U.S.; and the National Emissions Standards for Hazardous Air Pollutants for Utility Boilers ("Utility MACT") rule which will, for the first time, set federal limits for hazardous air pollutants such as mercury, lead, dioxin, and arsenic. Although our analysis considers only employment-related impacts under the new air regulations, the reality is these new standards will yield numerous other concrete economic benefits, including better public health from cleaner air, increased competitiveness from developing innovative technologies and mitigation of climate change. Moreover, increased employment during this critical five year period will also benefit severely stressed state budgets through increased payroll taxes and reduced unemployment benefit costs.

1. Office of Management and Budget (OMB). Informing Regulatory Decisions: 2003 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities. Office of Information and Regulatory Affairs, Office of Management and Budget, Washington DC. 2003.

2. U.S. Environmental Protection Agency, Our Nation's Air - Status and Trends through 2008, February 2010.

3. As depicted on the map in Figure 2, the Eastern Interconnection also includes the District of Columbia and small portions of Wyoming, Montana, New Mexico, and Texas. A small portion of South Dakota is within the Western Interconnection.

To estimate the job impacts, this study used a forecast of future pollution control installations, construction of new generation capacity, and coal plant retirements from a December 2010 study prepared by two researchers at Charles River Associates ("CRA").[4] Applying stringent EPA compliance requirements, including an assumption that the Utility MACT rule will require pollution controls on all coal-fired power plants by 2015, that study projected that between 2010 and 2015 the power sector will invest almost $200 billion on capital improvements, including almost $94 billion on pollution controls and over $100 billion on about 68,000 megawatts of new generation capacity. Constructing such new capacity and installing pollution controls will create a wide array of skilled, high-paying jobs, including engineers, project managers, electricians, boilermakers, pipefitters, millwrights and iron workers.

## Key findings:

- As detailed in Table ES.1 below, between 2010 and 2015, **these capital investments in pollution controls and new generation will create an estimated 1.46 million jobs or about 291,577 year-round jobs on average for each of those five years.**

**Table ES.1. Aggregate Employment Estimates from Capital Improvements: Construction, Installation, and Professional Jobs (between 2010 and 2015)**

| | DIRECT | DIRECT + INDIRECT |
|---|---|---|
| Pollution controls | 325,305 | 683,734 |
| New generation capacity | 312,617 | 774,151 |
| TOTAL | 637,922 | 1,457,885 |

*Note: All values reported in "job-years". One job-year equals one year of full-time employment.*

- As described in Table ES.2, transforming to a cleaner, modern fleet through retirement of older, less efficient plants, installation of pollution controls and construction of new capacity **will result in a net gain of over 4,254 operation and maintenance (O&M) jobs across the Eastern Interconnection**. Distribution of these O&M jobs will vary from state-to-state, depending on where coal plants are retired (O&M job reduction) and where new generation capacity is installed (O&M job gains).

4. "A Reliability Assessment of EPA's Proposed Transport Rule and Forthcoming Utility MACT", Shavel and Gibbs, CRA, December 16, 2010.

**Table ES.2. Employment Estimates of Net O&M Jobs Associated with Capital Improvements and Retirement of Coal Generation**

| | DIRECT | DIRECT + INDIRECT |
|---|---|---|
| Pollution controls | **7,170** | **14,077** |
| New generation capacity | **4,106** | **8,061** |
| Retirement of coal generation | **(9,109)** | **(17,884)** |
| NET TOTAL | **2,167** | **4,254** |

- Over the five years, investments in pollution controls and new generation capacity will create significant numbers of new jobs in each of the states within the Eastern Interconnection, more than offsetting any job reductions from projected coal plant closures.
  - The largest estimated job gains are in Illinois, (122,695), Virginia, (123,014), Tennessee, (113,138), North Carolina (76,966) and Ohio (76,240).[5]
  - In states with net O&M job reductions, projected gains in capital improvement jobs will provide enough work to fully offset the O&M job reductions.
  - The construction of pollution controls will create a significant, near-term increase in new jobs. O&M job reductions are likely to occur later in the period.

5. All values reported in "job-years". One job-year equals one year of full-time employment.

# I. INTRODUCTION

The CAA and its 1990 amendments have significantly reduced power sector air pollution. In 2011, EPA plans to implement regulations that will further reduce targeted emissions. Last July, the EPA proposed the Transport Rule to introduce new standards governing $SO_2$ and $NO_x$ emissions from 31 states and the District of Columbia, emissions that hinder the ability of downwind states to comply with national ambient air quality standards. In addition, EPA is required under court order to issue final Utility MACT regulations to limit electric generators' hazardous air pollutant emissions, including, for example, mercury, arsenic, chromium, nickel, lead, and hydrochloric acid.

**Merrimack Station**

**The Merrimack Station, New Hampshire's largest coal-fired power plant, constructed a scrubber to control $SO_2$ and mercury emissions. According to PSNH, the owner of the facility, the project provided more than 300 construction jobs for the three-year construction period.**

*Source: PSNH*

Focusing on the Eastern and Midwestern regions of the U.S., this study evaluates the employment impacts between 2010 and 2015 of these proposed and planned changes to EPA air regulations resulting from the power sector's investment in pollution controls and new generation, and from retirement of existing coal generation. For the purposes of this analysis, the study assumes stringent compliance requirements, including an assumption that the Utility MACT rule will require scrubbers and advanced particulate controls on all coal units by 2015.[6]

6. According to a study by Dr. Ira Shavel and Mr. Barclay Gibbs of Charles River Associates, "[o]thers...believe that MACT compliance may allow lower cost and relatively inexpensive dry scrubbing options using sorbents to capture acid gases and metals (e.g., trona with activated carbon injection)." A Reliability Assessment of EPA's Proposed Transport Rule and Forthcoming Utility MACT, Shavel and Gibbs, CRA, December 16, 2010, at p. 9.

**Deer Creek Station**

**Basin Electric began construction on the Deer Creek power plant, a 300-megawatt natural gas combined-cycle generation facility in South Dakota, in July 2010. The project will require about 350 workers at the peak of construction and 70 gas pipeline construction workers. The power plant is scheduled for commercial operation in June 2012 and will have about 30 full-time employees.**

*Source: Basin Electric*

The modeling projections focus on the years between 2010 and 2015, as that is the period during which companies will prepare to comply with the Utility MACT and Transport rules. For purposes of this analysis, we therefore assume the expenditures are spread over these years, and limit the employment effects from these capital investments to that period.

As detailed further in Appendix B, to estimate the employment impacts associated with the projected capital spending and coal plant retirements in the 36 states analyzed, we use the IMPLAN 3.0 input-output model, which is based on data from the U.S. Commerce Department's Bureau of Economic Analysis that has been finely disaggregated by sector and state.[7] Capital investments in pollution controls and new generation capacity and coal plant retirements[8] affect employment not only in the power generation sector, but also in sectors linked to electric generation, such as engineering services, coal, natural gas, metal fabrication, construction and business services. Based on the relationships between different economic sectors in the production of goods and services, the input-output model estimates the effects on employment resulting from an increase in spending on the products and services of a given industry. For example, the model estimates the number of jobs directly created in the design, engineering, and construction industries for each $1 million spent on pollution control retrofits and the construction of new generation capacity. As we explain below, the

7. The data used to construct the IMPLAN 3.0 model is based on 2008 figures – the most up-to-date picture of the sectoral relationships in the U.S. economy currently available.

8. Notably, not all the capital investments or coal plant retirements result directly from the new EPA air regulations, as reduced electricity demand, lower sustained fuel prices resulting from recent discoveries of abundant, domestic natural gas supplies, and state renewable energy programs also influence investment and retirement decisions.

model can also estimate the jobs indirectly created in other industries through that same $1 million in spending—for example, in industries such as steel components and hardware manufacturing.

**Mercer Station Pollution Control Retrofits**

**The Mercer station and Hudson station coal plants in New Jersey recently completed the installation of air pollution control systems. More than 1,600 construction workers were on the Mercer and Hudson facility job sites at the peak of construction.**

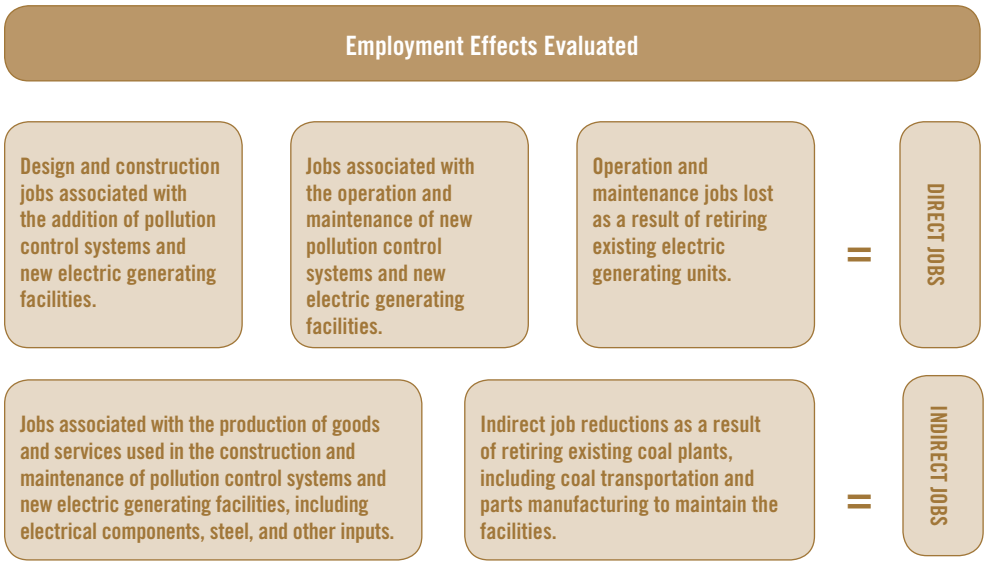
*Source: PSEG Corporation*

As described in Figure 1 below, our employment estimates include both direct and indirect job creation. First, it examines employment directly generated by capital investments in pollution controls and new generation capacity. Here the focus is on a wide array of skilled jobs associated with designing, procuring and installing pollution controls, and building new generation, including engineers, project managers, electricians, boilermakers, pipefitters, millwrights, iron-workers and security personnel.[9] As

9. For a more detailed discussion of occupational and skills requirements, see the National Commission on Energy Policy report, Task Force on America's Future Energy Jobs, available at www.bipartisanpolicy .org/sites/default/files/NCEP%20Task%20Force%20on%20America's%20Future%20Energy%20Jobs%20-%20Final%20Report.pdf.

these jobs are directly linked to these investment expenditures, they are created and maintained throughout the five year investment period. The direct effect represents jobs created by spending in the respective sector. For example, building new capacity involves expenditures to construct and install that capacity, including payments to new employees. Firms that install the new capacity will also have to purchase goods and services from other sectors, which in turn will create jobs in those other sectors: this "second round" of employment creation constitutes the indirect job effect.

**Figure 1. Scope of Employment Analysis**




*Note: The income associated with both direct and indirect employment will stimulate spending on goods and services that will result in additional job creation. These induced effects are not explicitly considered in this analysis.*

We do not explicitly consider a third source of job creation: "induced" jobs. Induced jobs are those created when individuals spend the money they earn from the direct and indirect employment. The size of the induced effects varies for a number of reasons, but will correlate with the number of direct and indirect jobs.[10] As this study calculates only the direct and indirect job impacts and excludes induced jobs, it provides a conservative estimate of the total employment impact.

10. Induced employment refers to the jobs generated when individuals in the direct and indirect jobs spend their income on goods and services. The size of the induced effects vary depending on the state of the economy. For example, if already employed individuals move from one job to another, the induced effects will be smaller (and could even be zero if there is no change in income). But if unemployed individuals move into the newly created jobs, as would be more likely given our current high unemployment rate, induced effects would likely be large.

**Merrimack Station**

**The scrubber retrofit at PSNH's Merrimack Station includes a concrete stack that stands at more than 445 feet. Concrete for the stack was delivered around-the-clock by the Redimix Company based in New Hampshire. By mid-July, when the shell of the stack was completed, a rotating shift of six Redimix drivers had delivered an estimated 1,060 cubic yards of concrete.**

*Source: PSNH*

The study also calculates estimated net changes in O&M jobs which, unlike construction and installation and related professional jobs, exist as long as the plants continue to generate electricity or the pollution control systems continue to operate. We project that although retiring older, less efficient capacity will lead to some O&M job reduction, installing pollution controls and building new generation will lead to a net increase in O&M jobs.

Estimating the employment impacts under EPA's air pollution regulations requires forecasts of future pollution control installations, new power plant construction and coal plant retirements. The forecasts used in this report are based on a detailed CRA modeling assessment entitled, "A Reliability Assessment of EPA's Proposed Transport Rule and Forthcoming Utility MACT," published in December 2010 by Dr. Ira Shavel and Mr. Barclay Gibbs of Charles River Associates (the "CRA Study").[11] The CRA Study used CRA's North American Electricity and Environment Model (NEEM) to estimate coal unit retirements, new capacity additions, and pollution control retrofits, taking into account the operating characteristics of existing capacity and the capital and operating costs of potential new capacity. As highlighted in Table 1 below, the CRA Study's predicted coal plant retirements are consistent with other similar assessments.

The CRA Study limited its analysis to the Eastern Interconnection where most of the nation's coal-fired generating capacity is located and where most of the capital investment associated with EPA's air pollution regulations is expected to occur. The Eastern Interconnection, one of four major power grids in the U.S. and Canada, comprises about 36 states (in part or whole) and the District of Columbia as shown in the map in Figure 2 below, accounts for much of the transmission system east of the Continental Divide[12] and contains approximately 73 percent of U.S. electricity generation. Moreover, as the Transport Rule only applies to states in the Eastern U.S., the estimated power sector changes projected below are concentrated in that part of the country.

11. Available at http://www.crai.com/Publications/listingdetails.aspx?id=13473

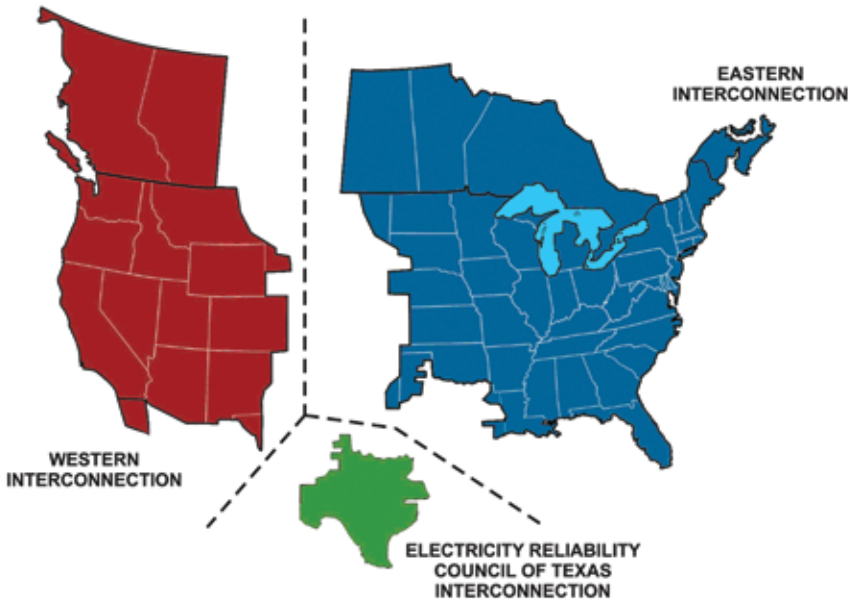
12. One notable exception is Texas, the majority of which is linked into a separate interconnected system.

### Table 1. Recent Projections of Coal Plant Retirements and Power Industry Investment

| | Author, Date | Projected Retirements | Notes |
|---|---|---|---|
| A Reliability Assessment of EPA's Proposed Transport Rule and Forthcoming Utility MACT | Shavel and Gibbs, Charles River Associates, December 2010 | 35 GW of coal plant retirements by 2015 (Eastern Interconnection) | Models utility MACT and Transport Rule |
| Potential Coal Plant Retirements Under Emerging Environmental Regulations | The Brattle Group, December 2010 | 28-39 GW of coal retirements by 2020 (Eastern Interconnection) | Models utility MACT and Transport Rule (scrubbers and SCR mandate) |
| Integrated Energy Outlook | ICF Consulting, January 2011 | 60 GW of coal plant retirements by 2018 (nationwide figure) | Models utility MACT, Transport Rule, coal ash, and cooling water regulations |

The CRA Study assumed stringent requirements to comply with the forthcoming Utility MACT regulations and proposed Transport Rule, including an assumption that by 2015 the Utility MACT rule will require scrubbers, activated carbon injection, and advanced particulate controls on all coal units. Furthermore, the CRA Study provided plant-level estimates of pollution control retrofits and retirements which could then be evaluated under the IMPLAN model.

### Figure 2. The Eastern Interconnection and Other North American Electric System Interconnections



# II. EASTERN INTERCONNECTION EMPLOYMENT IMPACTS UNDER PLANNED EPA RULES

This report calculates estimated employment effects in the Eastern Interconnection in two broad categories: (1) construction, installation and professional jobs from capital investment in pollution controls and new generation capacity; and (2) net O&M jobs directly and indirectly associated with those capital improvements and O&M job reductions from retiring older, less efficient coal capacity.

## Capital Improvements Spending on Pollution Controls and New Generation Capacity

The CRA Study projects that between 2010 and 2015 the electricity power sector will spend an estimated $196 billion on capital improvements under EPA's new utility MACT and Transport rules: $93.6 billion on pollution controls and $102.4 billion on about 68,000 megawatts of new generation capacity. Expenditures on pollution controls are assumed to include four technologies: (1) activated carbon injection ("ACI") to control mercury emissions; (2) activated carbon injection with fabric filters ("ACI+") to control mercury and other hazardous air pollutant emissions; (3) flue gas desulfurization ("FGD") or "scrubbers" to control $SO_2$ and hazardous air pollutant emissions; and (4) selective catalytic reduction ("SCR") to control $NO_x$ emissions.

**Jeffrey Energy Center**

**The Jeffrey Energy Center, the largest coal-fired power plant in Kansas, upgraded the scrubbers at the facility to achieve greater than 95 percent $SO_2$ control. The project started in 2007 and was completed in 2009. The project required over 1,300 tons of structural steel and more than 850 construction workers were on-site at the peak of construction.**

*Source: Westar*

Using the widely endorsed and proven IMPLAN 3.0 input-output model, we estimate the direct and indirect employment effects of substantial pollution control expenditures and resulting job impacts. In addition to investments in pollution controls, we also estimate the employment impacts of investment in new generation capacity involving nine different technologies: (1) advanced coal technologies; (2) integrated gasification combined cycle, ("IGCC") (coal); (3) combined cycle (natural gas); (4) combustion turbine (natural gas); (5) nuclear; (6) municipal waste/landfill gas; (7) biomass; (8) solar (photovoltaic); and (9) wind.

As with pollution controls, the design and construction of new generation capacity requires substantial expenditures for a variety of goods and services. Our employment estimates consider how these expenditures vary by technology. For example, landfill gas capacity involves expenditures on turbines, air and gas compressors, pipes and pipefitting, iron and steel milling, environmental control machinery, and construction services.

The capital investments will generate direct and indirect jobs in a range of sectors involving skilled and professional occupations. Direct jobs would include, for example, new non-residential construction, metal fabrication, and engineering. Indirect jobs would include steel manufacturing, catalyst system manufacturing, control system manufacturing, and transportation services.

Table 2 presents estimates of the aggregate jobs created over five years through investments on capital improvements and new capacity. Between 2010 and 2015, the almost $94 billion of investment in pollution controls would generate an estimated 325,305 direct jobs and an estimated 683,734 direct and indirect jobs. The $102.4 billion of investment in new generation would create a total of 312,617 direct jobs and 774,151 direct and indirect jobs. Taken together, projected investments in capital improvements under the new EPA regulations would create an estimated 1,457,885 jobs over the next five years, or over 290,000 full-time jobs on average per year over the five year period.

**Table 2. Aggregate Employment Estimates from Capital Improvements: Construction, Installation, and Professional Jobs (between 2010 and 2015)**

| | DIRECT | DIRECT + INDIRECT |
|---|---|---|
| Pollution controls | **325,305** | **683,734** |
| New generation capacity | **312,617** | **774,151** |
| TOTAL | **637,922** | **1,457,885** |

*Note: All values reported as "job-years". One job-year equals one year full-time employment.*

To reflect the reality that construction, installation and professional jobs will be realized over the period during which the investments occur, the 1,457,885 figure represents total jobs created over the five year period, with each job-year representing a single job that lasts one year.[13] If all the expenditures were to happen in a single year,

13. The characteristics of the jobs – in terms of benefits, hours of work, and wages – would reflect the current composition of jobs in the industries impacted by the construction and installation expenditures.

1,457,885 jobs would be created that year. However, a more realistic assumption would be that the pollution control and new generation expenditures would be spread out over time. For purposes of illustration, assuming that 10 percent of the expenditures will occur in the first year, 15 percent in the second year, and 25 percent in each of the three subsequent years, the job creation in three peak years would be 25 percent of 1,457,885, or 364,471 jobs per year.

## O&M Jobs

In addition to jobs associated with the design, construction and installation of pollution controls and new generation, the model also projects more permanent O&M jobs. Pollution controls, for example, need workers to maintain systems and handle waste. Similarly, power plants require workers to operate and maintain their equipment. We estimate the O&M jobs associated with these capital investments above by first estimating the O&M costs associated with the capital investment and then use the input-output framework to estimate the employment impacts.

In the case of older, less efficient existing capacity, much of which is already challenged by sustained low natural gas prices and reduced demand, companies may choose to retire existing capacity rather than installing pollution control systems, causing some O&M job reductions.[14] The CRA Study projects 35 gigawatts of coal plant retirements by 2015 in the Eastern Interconnection. To estimate the direct employment impact of predicted retirements, we did not use the input-output framework, but instead used detailed finance and operation data which the Federal Energy Regulatory Commission ("FERC") requires utilities to submit annually. Current employment levels from the FERC forms were matched to retired plants whenever possible. For retired plants with no matched employment data, we used state averages of employment per MW derived from plants in the same state with such employment data. We did, however, apply the input-output model to estimate indirect job losses from capacity retirements.

Table 3 shows the net Eastern Interconnection O&M employment impacts. Pollution control investments would create 7,170 O&M direct jobs and the new capacity investments would create 4,106 direct O&M jobs, offset by a reduction of 9,109 direct O&M jobs through capacity retirements, for a net gain of 2,167 direct O&M jobs. Combining both direct and indirect jobs results in a net gain of 4,254 jobs for the states analyzed.

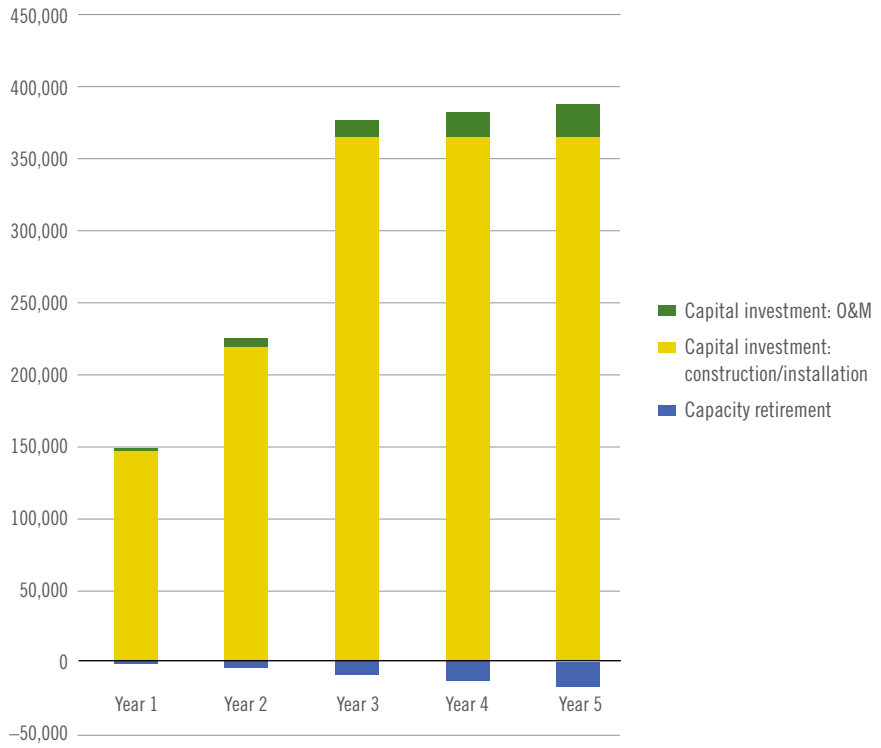
14. Some retirements may also generate short-lived gains in employment through necessary expenditures to shut down a facility (e.g. demolition, waste removal, etc). Also, companies may redeploy workers to other plants or offer early retirement opportunities. We do not, however, consider these possibilities.

### Table 3. Estimates of Net O&M Jobs Associated with Capital Improvements and Retirement of Capacity

| | DIRECT | DIRECT + INDIRECT |
|---|---|---|
| Pollution controls | 7,170 | 14,077 |
| New generation capacity | 4,106 | 8,061 |
| Retirement of existing capacity | (9,109) | (17,884) |
| NET TOTAL | 2,167 | 4,254 |

Figure 2 summarizes Eastern Interconnection direct and indirect employment effects in the three main categories of job creation and reductions: (1) construction, installation and professional jobs created through new capital investment, (2) O&M jobs created through new capital investment, and (3) job reductions due to capacity retirements. Again, we assume that 10 percent of the adjustments under the new EPA standards will occur in the first year, 15 percent in the second year, and 25 percent in each of the three subsequent years. Clearly, construction, installation and professional jobs dominate the picture. However, more O&M jobs are created as power companies adapt to the new standards.

### Figure 3. Estimates of Direct and Indirect Employment Effects Over Time (between 2010 and 2015)



# III. STATE-LEVEL ANALYSIS OF EMPLOYMENT IMPACTS

Using job impact estimates from projected pollution controls and new generation investments and capacity retirements, we also calculated state-level impacts for the states in the Eastern Interconnection.

## State-level Spending on Pollution Controls and New Generation

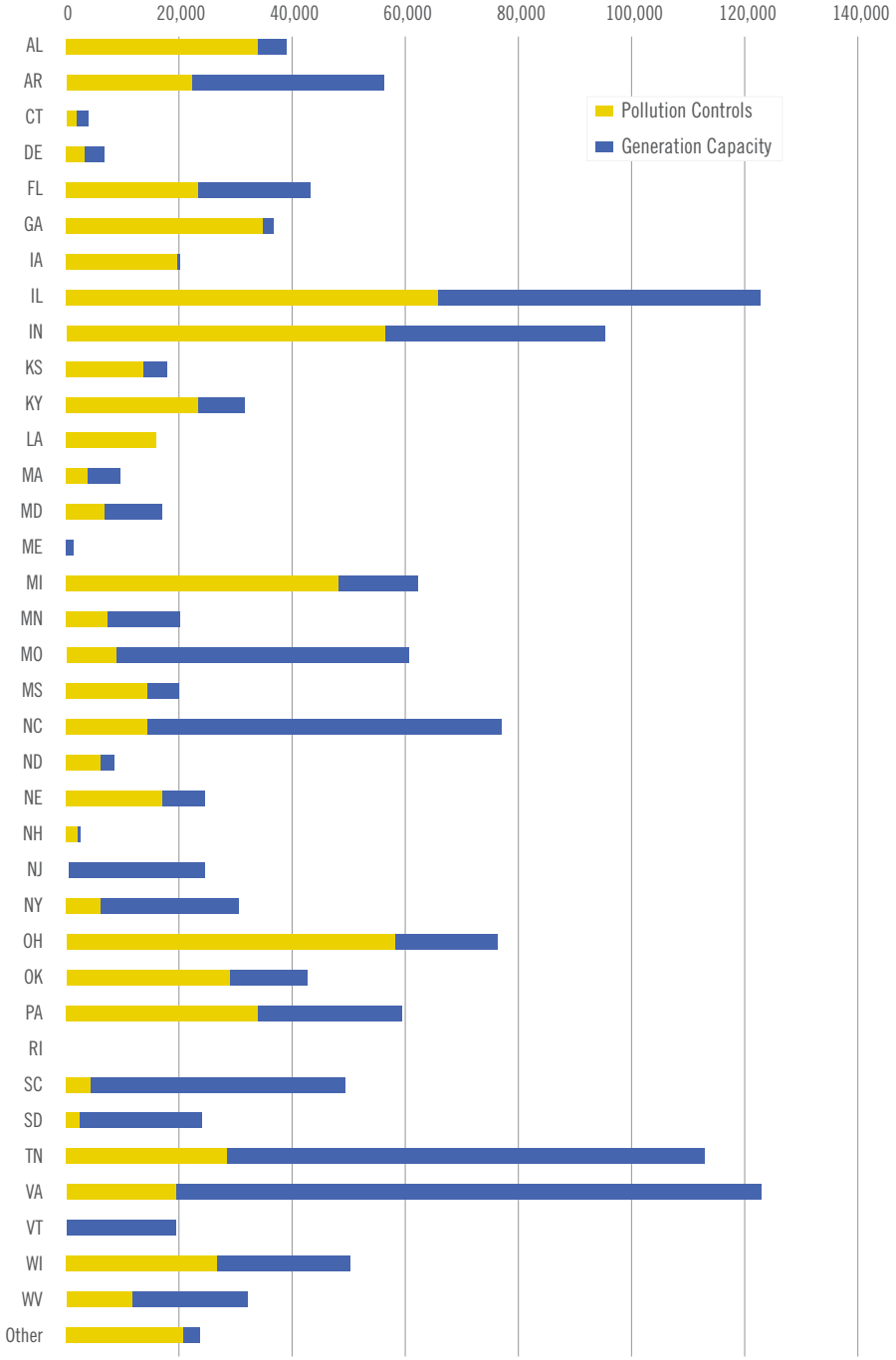
Table A1 in the appendix summarizes state-level capital improvements in terms of: (1) total spending on pollution controls; (2) total increase in energy capacity expressed as megawatts; and (3) capital expenditures needed to increase capacity by the relevant number of megawatts.

To estimate state-specific employment impacts, we used the same methodology as with the Eastern Interconnection analysis except that we relied on individual state input-output models. Figure 4 below shows estimated direct and indirect jobs created through both the pollution control and new generation investments detailed in Table A1. (Table A2 in the appendix summarizes the data used in Figure 4.) Not surprisingly, the number of jobs created tracks closely with the estimated spending. For example, Illinois, which has the highest projected spending on pollution controls over the five year investment period, has the greatest number of related jobs: 65,600 direct and indirect jobs. Similarly, Virginia with the highest projected investment in new capacity, experiences the largest number of related jobs: 103,365 direct and indirect jobs.

## State-level Estimates of O&M Jobs from Capital Improvements

Table A3 in the appendix presents state-level estimates of the O&M jobs associated with the capital investments detailed in Table A1. Permanent O&M jobs increase with the amount of the capital investments and vary with the composition of technologies utilized. Although states with zero spending gain no O&M jobs, most states gain substantial numbers of such jobs. For example, Ohio gains over 1,100 O&M jobs (direct and indirect) from pollution control investments, and Virginia gains over 920 O&M jobs (direct and indirect) from new capacity investments.

## Figure 4. Estimated Construction, Installation, and Other Professional Jobs Gains from Investment in Capital Improvements




Note: All values reported in "job-years". One job-year equals one year of full-time employment.

## Table 4. Summary of Direct and Indirect State-Level Job Impacts from Capital Improvements and Coal Plant Retirements

| | Capital Improvements | | Retirements |
|---|---|---|---|
| | Construction, Installation, & Professional Job Gains over 5 years (in job years) | O&M Job Gains | O&M Job Reductions |
| AL | 38,755 | 764 | (1,184) |
| AR | 56,110 | 690 | 0 |
| CT | 3,858 | 41 | 0 |
| DE | 6,542 | 114 | (219) |
| FL | 43,106 | 699 | (970) |
| GA | 36,465 | 584 | (1,700) |
| IA | 19,899 | 386 | (475) |
| IL | 122,695 | 1,429 | (549) |
| IN | 95,193 | 1,413 | (563) |
| KS | 17,812 | 342 | (179) |
| KY | 31,477 | 875 | (982) |
| LA | 15,842 | 297 | (145) |
| MA | 9,545 | 66 | (157) |
| MD | 16,922 | 226 | (180) |
| ME | 1,279 | 19 | 0 |
| MI | 62,346 | 987 | (1,124) |
| MN | 20,141 | 309 | (542) |
| MO | 60,512 | 1,727 | (271) |
| MS | 19,803 | 360 | (183) |
| NC | 76,966 | 973 | (1,014) |
| ND | 8,207 | 193 | (58) |
| NE | 24,331 | 208 | (217) |
| NH | 2,420 | 40 | (155) |
| NJ | 24,255 | 316 | (123) |
| NY | 30,496 | 303 | (187) |
| OH | 76,240 | 1,365 | (1,772) |
| OK | 42,651 | 623 | 0 |
| PA | 59,243 | 794 | (1,272) |
| RI | 359 | 323 | 0 |
| SC | 49,311 | 757 | (968) |
| SD | 23,909 | 379 | 0 |
| TN | 113,138 | 1,379 | (869) |
| VA | 123,014 | 1,225 | (369) |
| VT | 19,107 | 197 | 0 |
| WI | 50,233 | 784 | (874) |
| WV | 32,253 | 675 | (583) |
| Other | 23,453 | 277 | (2) |
| TOTAL | 1,457,885 | 22,138 | (17,884) |

*Note: Employment estimates taken from Tables A2, A3, and A4.*

## State-level Estimates of Job Reductions from Retirements

Using FERC data for direct job reductions and state specific input-output models for indirect job losses, Table A4 in the appendix presents state-level estimates of job reductions from coal plant retirements. Notably, the CRA Study's projected coal plant retirements are only partly attributable to stricter EPA regulations. According to the CRA Study, substantial retirements are also driven by reduced demand and low priced, abundant natural gas.[15]

Furthermore, the estimated job reductions in Table A4 will be offset by gains in construction, installation, and professional jobs and O&M jobs due to capital investments in pollution controls and new generation capacity. As such, it is important to examine the net change in employment from all of these sources. To reflect the total impact of capital investments and coal plant retirements between 2010 and 2015, Table 4 provides a comprehensive side-by-side comparison using the estimated gains in construction, installation and professional jobs from Table A2, O&M job gains from capital improvements from Table A3 and job reductions due to coal plant retirements from Table A4.

Significantly, when considering both direct and indirect effects and all sources of job creation and job reductions, all of the states show a net gain in employment over the analysis period.

15. "However, given the recent discoveries of abundant, domestic natural gas supplies, a competing fuel for electric generation, as well as reduced electricity demand, coal plant owners may elect to retire some existing plants rather than investing the capital necessary to install pollution controls," *A Reliability Assessment of EPA's Proposed Transport Rule and Forthcoming Utility MACT*, Shavel and Gibbs, CRA, December 16, 2010, at p. 3.

## CONCLUSION

After evaluating the employment impacts of the electric power sector's transformation to a cleaner, modern fleet, we conclude that the installation of air pollution controls and construction of new generation under the proposed and planned EPA air rules will lead to a net job gain in the Eastern Interconnection states.

The installation, design and construction of pollution controls and additional generation capacity will create the greatest number of new jobs. Although some O&M jobs will be lost because of projected coal plant retirements, these losses will be offset by new O&M jobs from pollution control and new generation capacity investments, resulting in net job gains across all the states studied.

Notably as well, this report only considered the net employment impacts from capital investments in pollution controls and new generation and from coal plant retirements. When evaluating the overall impact of new EPA air regulations, one must also recognize that the positive job impacts detailed in this study do not provide the entire picture, as the air regulations will also provide substantial economic benefits from cleaner air, improved public health and increased competitiveness through innovative technologies.

# APPENDIX A

## Table A1. Pollution Controls and New Generation Capacity Investments from the CRA Study

| State | Pollution Controls | Additional Installed Capacity (MW) | Investment in New Capacity |
|---|---|---|---|
| AL | $4.1 billion | 766 | $691 million |
| AR | $2.4 billion | 1,472 | $4.2 billion |
| CT | $229 million | 220 | $381 million |
| DE | $414 million | 585 | $687 million |
| FL | $2.7 billion | 1,793 | $2.3 billion |
| GA | $4.3 billion | 89 | $228 million |
| IA | $2.5 billion | 17 | $46 million |
| IL | $7.6 billion | 2,946 | $7.3 billion |
| IN | $7.2 billion | 2,613 | $4.8 billion |
| KS | $1.8 billion | 225 | $539 million |
| KY | $3.8 billion | 898 | $1.1 billion |
| LA | $2.1 billion | — | — |
| MA | $504 million | 108 | $653 million |
| MD | $1.0 billion | 2,558 | $3.3 billion |
| ME | — | 86 | $201 million |
| MI | $6.3 billion | 1,033 | $1.7 billion |
| MN | $1.1 billion | 652 | $1.4 billion |
| MO | $6.6 billion | 4,103 | $6.8 billion |
| MS | $1.5 billion | 773 | $754 million |
| NC | $2.0 billion | 6,488 | $7.9 billion |
| ND | $1.1 billion | 175 | $454 million |
| NE | $2.2 billion | 403 | $1.0 billion |
| NH | $266 million | 20 | $57 million |
| NJ | $51 million | 3,100 | $3.8 billion |
| NY | $944 million | 1,826 | $3.5 billion |
| OH | $7.1 billion | 1,792 | $2.2 billion |
| OK | $3.5 billion | 993 | $1.6 billion |
| PA | $4.7 billion | 2,321 | $3.3 billion |
| RI | — | 20 | $57 million |
| SC | $695 million | 5,554 | $5.8 billion |
| SD | $269 million | 3,083 | $3.0 billion |
| TN | $3.6 billion | 4,868 | $9.9 billion |
| VA | $2.6 billion | 12,531 | $13.8 billion |
| VT | — | 1,359 | $3.0 billion |
| WI | $3.4 billion | 1,285 | $2.9 billion |
| WV | $2.6 billion | 960 | $2.7 billion |
| Other | $2.6 billion | 333 | $403 million |
| TOTAL | $93.6 billion | 68,047 | $102.4 billion |

## Table A2. Estimated Construction, Installation, and Other Professional Job Gains from Investment in Capital Improvements

| State | Pollution Controls | | Generation Capacity | | Total |
|---|---|---|---|---|---|
| | Direct | Direct + Indirect | Direct | Direct + Indirect | Direct + Indirect |
| AL | 16,298 | 33,495 | 1,955 | 5,260 | 38,755 |
| AR | 11,334 | 22,409 | 14,325 | 33,701 | 56,110 |
| CT | 799 | 1,617 | 844 | 2,240 | 3,858 |
| DE | 1,649 | 3,191 | 1,626 | 3,350 | 6,542 |
| FL | 9,856 | 23,271 | 6,552 | 19,834 | 43,106 |
| GA | 15,642 | 34,836 | 503 | 1,629 | 36,465 |
| IA | 10,282 | 19,602 | 112 | 297 | 19,899 |
| IL | 30,594 | 65,600 | 21,928 | 57,096 | 122,695 |
| IN | 27,763 | 56,648 | 15,788 | 38,545 | 95,193 |
| KS | 7,067 | 13,706 | 1,720 | 4,106 | 17,812 |
| KY | 11,892 | 23,222 | 3,155 | 8,255 | 31,477 |
| LA | 8,004 | 15,842 | 0 | 0 | 15,842 |
| MA | 1,735 | 3,678 | 2,445 | 5,867 | 9,545 |
| MD | 3,236 | 6,967 | 4,797 | 9,955 | 16,922 |
| ME | 0 | 0 | 570 | 1,279 | 1,279 |
| MI | 21,534 | 48,097 | 5,425 | 14,249 | 62,346 |
| MN | 3,557 | 7,590 | 5,067 | 12,551 | 20,141 |
| MO | 4,237 | 8,902 | 20,668 | 51,610 | 60,512 |
| MS | 7,514 | 14,202 | 2,323 | 5,601 | 19,803 |
| NC | 6,485 | 14,275 | 24,689 | 62,691 | 76,966 |
| ND | 3,190 | 5,971 | 1,073 | 2,237 | 8,207 |
| NE | 8,261 | 16,968 | 3,196 | 7,363 | 24,331 |
| NH | 1,031 | 2,068 | 122 | 352 | 2,420 |
| NJ | 134 | 308 | 9,157 | 23,946 | 24,255 |
| NY | 2,960 | 6,155 | 9,998 | 24,341 | 30,496 |
| OH | 26,299 | 58,175 | 6,407 | 18,065 | 76,240 |
| OK | 14,380 | 28,898 | 5,709 | 13,753 | 42,651 |
| PA | 15,157 | 33,833 | 9,096 | 25,411 | 59,243 |
| RI | 0 | 0 | 118 | 359 | 359 |
| SC | 2,038 | 4,421 | 17,625 | 44,889 | 49,311 |
| SD | 1,247 | 2,382 | 9,060 | 21,527 | 23,909 |
| TN | 13,455 | 28,445 | 35,956 | 84,693 | 113,138 |
| VA | 9,450 | 19,648 | 41,835 | 103,365 | 123,014 |
| VT | 0 | 0 | 9,323 | 19,107 | 19,107 |
| WI | 12,555 | 26,801 | 8,837 | 23,431 | 50,233 |
| WV | 6,455 | 11,746 | 9,692 | 20,507 | 32,253 |
| Other | 9,214 | 20,764 | 919 | 2,688 | 23,453 |
| TOTAL | 325,305 | 683,734 | 312,617 | 774,151 | 1,457,885 |

Note: All values reported in "job-years". One job-year equals one year of full-time employment.

## Table A3. Estimated Operating and Maintenance Job Gains from Investments in Capital Improvements

| State | Pollution Controls | | Generation Capacity | | Total |
|---|---|---|---|---|---|
| | Direct | Direct + Indirect | Direct | Direct + Indirect | Direct + Indirect |
| AL | 359 | 684 | 42 | 80 | 764 |
| AR | 229 | 417 | 150 | 273 | 690 |
| CT | 11 | 24 | 8 | 17 | 41 |
| DE | 34 | 60 | 30 | 54 | 114 |
| FL | 202 | 461 | 105 | 238 | 699 |
| GA | 274 | 563 | 10 | 20 | 584 |
| IA | 212 | 381 | 3 | 5 | 386 |
| IL | 481 | 1,007 | 202 | 422 | 1,429 |
| IN | 564 | 1,060 | 188 | 352 | 1,413 |
| KS | 160 | 289 | 30 | 53 | 342 |
| KY | 398 | 738 | 74 | 137 | 875 |
| LA | 146 | 297 | 0 | 0 | 297 |
| MA | 28 | 59 | 4 | 8 | 66 |
| MD | 31 | 81 | 55 | 145 | 226 |
| ME | 0 | 0 | 10 | 19 | 19 |
| MI | 405 | 850 | 65 | 137 | 987 |
| MN | 89 | 172 | 71 | 137 | 309 |
| MO | 615 | 1,157 | 304 | 570 | 1,727 |
| MS | 155 | 273 | 50 | 87 | 360 |
| NC | 162 | 306 | 355 | 667 | 973 |
| ND | 89 | 162 | 17 | 31 | 193 |
| NE | 60 | 171 | 13 | 37 | 208 |
| NH | 18 | 35 | 2 | 5 | 40 |
| NJ | 50 | 105 | 102 | 212 | 316 |
| NY | 58 | 114 | 97 | 188 | 303 |
| OH | 599 | 1,161 | 106 | 204 | 1,365 |
| OK | 241 | 489 | 66 | 134 | 623 |
| PA | 255 | 571 | 100 | 223 | 794 |
| RI | 0 | 0 | 132 | 323 | 323 |
| SC | 68 | 124 | 352 | 634 | 757 |
| SD | 24 | 44 | 184 | 336 | 379 |
| TN | 350 | 634 | 412 | 745 | 1,379 |
| VA | 136 | 297 | 428 | 928 | 1,225 |
| VT | 0 | 0 | 101 | 197 | 197 |
| WI | 302 | 560 | 121 | 224 | 784 |
| WV | 275 | 485 | 108 | 190 | 675 |
| Other | 89 | 248 | 12 | 30 | 277 |
| TOTAL | 7,170 | 14,077 | 4,106 | 8,061 | 22,138 |

## Table A4. Estimated Job Reductions from Coal Plant Retirements

| State | Capacity (MW) Retired | Job Reductions | |
|---|---|---|---|
| | | Direct | Direct + Indirect |
| AL | 2,197 | 623 | 1,184 |
| AR | 0 | 0 | 0 |
| CT | 0 | 0 | 0 |
| DE | 447 | 123 | 219 |
| FL | 1,583 | 427 | 970 |
| GA | 3,018 | 831 | 1,700 |
| IA | 1,066 | 265 | 475 |
| IL | 901 | 263 | 549 |
| IN | 1,440 | 300 | 563 |
| KS | 287 | 99 | 179 |
| KY | 1,917 | 531 | 982 |
| LA | 259 | 71 | 145 |
| MA | 271 | 75 | 157 |
| MD | 250 | 69 | 180 |
| ME | 0 | 0 | 0 |
| MI | 1,926 | 537 | 1,124 |
| MN | 1,040 | 282 | 542 |
| MO | 479 | 144 | 271 |
| MS | 378 | 104 | 183 |
| NC | 3,009 | 540 | 1,014 |
| ND | 116 | 32 | 58 |
| NE | 276 | 76 | 217 |
| NH | 208 | 80 | 155 |
| NJ | 216 | 59 | 123 |
| NY | 348 | 96 | 187 |
| OH | 3,851 | 917 | 1,772 |
| OK | 0 | 0 | 0 |
| PA | 2,070 | 570 | 1,272 |
| RI | 0 | 0 | 0 |
| SC | 2,003 | 537 | 968 |
| SD | 0 | 0 | 0 |
| TN | 1,746 | 481 | 869 |
| VA | 683 | 170 | 369 |
| VT | 0 | 0 | 0 |
| WI | 1,437 | 474 | 874 |
| WV | 1,606 | 331 | 583 |
| Other | 2 | 1 | 2 |
| TOTAL | 35,029 | 9,109 | 17,884 |

# APPENDIX B

## Methodology and Assumptions

### a. Response of the Electric Sector to Proposed and Planned EPA Air Regulations

The December 2010 CRA Study developed forecasts of the electricity generation sector's responses to EPA's proposed and planned air regulations. For these forecasts, CRA researchers used a model of the energy sector, the North American Electricity and Environment Model (NEEM), to predict changes in capacity and investment expenditures[16]. We used the modeled responses to estimate employment impacts. The specific responses include: (1) expenditures on pollution control technologies (ACI, ACI+, FGD, and SCR), (2) additions to generating capacity involving nine technologies: advanced coal, IGCC, combined cycle, combustion turbine, nuclear, municipal waste, biomass, solar PV, and wind, and (3) coal plant retirements.

The CRA Study included information on pollution controls, new generation capacity and coal plant retirements was provided at the plant level. We aggregated this information to state-level and Eastern Interconnection-wide estimates of retirements and investment in pollution controls and new generation capacity.

### b. Linking Expenditures on Pollution Controls and Generation Capacity Additions to Sectors in the Input-Output Model

Jim Staudt of Andover Technology Partners, provided details of the precise categories of expenditures associated with each of the four pollution control technologies. Dr. Staudt is President of Andover Technology Partners and a nationally recognized expert on air pollution control, with a Ph.D in Engineering from the Massachusetts Institute of Technology. These expenditure breakdowns were linked to PERI's IMPLAN 3.0 input-output model to generate employment multipliers. Select examples of the types of expenditures/activities used to generate the employment estimates include:

ACI and ACI+: equipment (e.g. sorbent injector and disposal systems), engineering services, duct work, and electrical installation services.

FGD scrubbers: water treatment systems, chimney construction, fans & ductwork, engineering services, contractor services.

SCR: reactor housing construction and installation, ammonia handling systems, ductwork & fans, engineering services.

We matched each of these spending areas with an industrial sector in the input-output model. backing out some retrofits that were known to have been completed in 2010.

16. "Appendix B: Modeling and Methodology," *A Reliability Assessment of EPA's Proposed Transport Rule and Forthcoming Utility MACT*, Shavel and Gibbs, CRA, December 16, 2010, at p. 35-37.

We then combined individual spending categories into a single aggregate category for each of the four technologies (ACI, ACI+, FGD, and SCR), using individual expenditure shares as weights. We then generated employment estimates associated with expenditures on each of the four pollution control technologies using the input-output model.

We estimated employment creation from expenditures on generation capacity for each of the nine technologies using a similar procedure. Activities involved in the installation of new generation capacity are identified from industry sources. These activities are then matched with the relevant sectors in the input-output model to produce employment multipliers.

The sum of the indirect employment effects across the Eastern interconnection states based on the state-level input-output models will fall short of the aggregate estimates presented in Table 1, which are based on a national input-output model. The reason for the discrepancy is that indirect effects will be lower at the state level than at the Eastern Interconnection level. For example, based on the CRA Study's estimate, Ohio is expected to spend about $7.1 billion on pollution control technologies. However, firms installing these capital improvements may purchase goods and services from other states. These indirect purchases will create jobs in other states—not Ohio. In contrast, the aggregate estimates include all indirect effects from all the states combined. The state-level input-output models produce estimates of employment effects in one state only. They do not allow us to allocate the indirect effects that occur outside the state to other specific states (e.g., we do not know how much of the spending by Ohio's construction industry is on inputs from Missouri, for instance).

To account for this discrepancy, we allocate the difference between the total employment estimates (direct and indirect) from the national input-output model and the sum of the state-level estimates according to each state's share of the aggregate employment effects across all states.

### d. Estimating operating and maintenance expenditures associated with capital investments.

Estimates of O&M expenditures associated with investments in pollution controls are based on estimates compiled by Industrial Economics, Inc. of Cambridge, MA, for FGD scrubbers used in electric generation applications. The O&M estimates are derived from the EPA's Coal Utility Environmental Cost (CUE Cost) spreadsheet. The cost estimates produced by Industrial Economics include a 30 percent premium for administrative employment. To restrict the analysis to O&M jobs, we do not include this premium in the employment estimates, in order to restrict the analysis to O&M jobs. O&M expenditures total an estimated 6.6 cents for each dollar invested in FGD technologies. We assume that this same ratio of O&M costs to investment applies to the other pollution control technologies: ACI, ACI+, and SCR. We then estimate total O&M expenditures from the total dollar value of investments in pollution controls. The input-output model generates employment estimates based on these expenditures.

Estimates of O&M expenditures linked to new generation capacity are based on O&M expenditures used by the U.S. Energy Information Administration (EIA). Fixed and

variable O&M costs associated with each of the nine technologies are taken from the EIA publication, *Assumptions to the 2010 Annual Energy Outlook* (Table 8.2). For purposes of estimating O&M employment, O&M costs per kilowatt of installed capacity are computed assuming peak summer capacity. The O&M cost per KW can then be used to calculate total O&M expenditures, in response to changes in emissions regulations, associated with the predicted state-level and Eastern Interconnection investments in new generation capacity.

### e. Estimates of direct employment reductions from coal plant retirements

Current employment levels were obtained from FERC forms for some of these retired plants. FERC employment numbers are matched to retired plants whenever possible. For retired plants with no matched employment data, we used state averages of employment per MW derived from plants in the same state that do have such employment data. For states with planned retirements and no employment data whatsoever, national averages of employment per MW are used.

Ceres
99 Chauncy Street
Boston, MA 02111
T: 617-247-0700
F: 617-267-5400
www.ceres.org

©2011 Ceres

# EXHIBIT 7

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

# Economic Benefits to Local Communities from National Park Visitation and Payroll, 2010

Natural Resource Report NPS/NRSS/EQD/NRR—2011/481

**ON THE COVER**
Businesses near Black Canyon of the Gunnison National Park, Colorado
Photograph by NPS/Margaret Littlejohn

# Economic Benefits to Local Communities from National Park Visitation and Payroll, 2010

Natural Resource Report NPS/NRSS/EQD/NRR—2011/481

Daniel J. Stynes

Department of Community, Agriculture, Recreation and Resource Studies
Michigan State University
East Lansing, Michigan 48824-1222

December 2011

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service Associate Director for 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.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

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.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Environmental Quality Division (www.nature.nps.gov/socialscience/index.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:

Stynes, D. J. 2011. Economic benefits to local communities from national park visitation and payroll, 2010. Natural Resource Report NPS/NRSS/EQD/NRR—2011/481. National Park Service, Fort Collins, Colorado.

NPS 999/112136, December 2011

# Contents

Page

Contents ..... iii
Figures and Tables ..... iv
Executive Summary ..... v
Introduction ..... 1
2010 Updates ..... 1
Recreation Visits ..... 2
Visitor Spending ..... 2
Local Impacts of Visitor Spending ..... 4
  Economic Significance ..... 6
  Economic Impacts ..... 6
National Economic Significance of NPS Visitor Spending ..... 7
Impacts of NPS Payrolls ..... 8
State-by-State Impact Estimates ..... 9
Methods ..... 10
Errors and Limitations ..... 12
References ..... 15
Appendices ..... 17

# Figures and Tables

Page

**Figure 1**. Distribution of National Park Visitor Spending ..... 4

**Table 1**. National Park Visitor Spending in the Local Area by Segment, 2010..... 3

**Table 2**. National Park Visitor Spending by Segment, 2010 ..... 4

**Table 3**. Economic Significance of National Park Visitor Spending to Local Economies, 2010..... 5

**Table 4**. Economic Impacts of National Park Visitor Spending on Local Economies, 2010..... 5

**Table 5**. Economic Significance of National Park Visitor Spending on National Economy, 2010 ..... 7

**Table 6**. NPS Payroll Impacts on Local Economies, 2010 ..... 8

**Table 7**. Combined Impacts on Local Economies–Visitor Spending and Payroll ..... 9

**Table 8.** Combined Impacts on National Economy–Visitor Spending and Payroll..... 9

# Executive Summary

The National Park System received 281 million recreation visits in 2010. Park visitors spent $12.13 billion in local gateway regions (within roughly 60 miles of the park). Visitors staying outside the park in motels, hotels, cabins and bed and breakfasts accounted for 56% of the total spending. Half of the spending was for lodging and meals, 19% for gas and local transportation, 10% for amusements, 8% for groceries, and 13% for other retail purchases.

The contribution of this spending to the national economy is 258,400 jobs, $9.8 billion in labor income, and $16.6 billion in value added[1]. The direct effects of visitor spending are at the local level in gateway regions around national parks. Local economic impacts were estimated after excluding spending by visitors from the local area (9.8% of the total). Combining local impacts across all parks yields a total local impact including direct and secondary effects of 156,280 jobs, $4.68 billion in labor income, and $7.65 billion value added. The four local economic sectors most directly affected by non-local visitor spending are lodging, restaurants, retail trade, and amusements. Visitor spending supports 43,160 jobs in restaurants and bars, 32,000 jobs in lodging sectors, 23,000 jobs in retail and wholesale trade, and 18,560 jobs in amusements.

Parks also impact the local and national economies through the NPS payroll. In Fiscal Year 2010 the National Park Service employed 26,031 people with a total payroll of $1,709 million in wages, salaries, and payroll benefits. Including the induced effects of the spending of NPS wages and salaries in the local region, the total local economic impacts of park payrolls are $1.95 billion in labor income, $2.16 billion in value added, and 32,407 jobs (including NPS jobs). The impacts of the park payroll on the national economy are $2.41 billion in labor income, $2.96 billion in value added, and 41,700 jobs

Combining the impacts of non-local visitor spending and NPS payroll-related spending yields a total impact of 300,000 jobs nationally of which 189,000 are in the local regions around national parks.

[1] National estimates use multipliers for the U.S. economy.

# Introduction

This report provides updated estimates of National Park Service (NPS) visitor spending for 2010 and estimates the economic impacts of visitor spending and the NPS payroll on local economies. Visitor spending and impacts are estimated using the Money Generation Model version 2 (MGM2) model (Stynes et. al. 2000) based on calendar year 2010 park visits, spending averages from park visitor surveys, and local area economic multipliers. Impacts of the NPS payroll are estimated based on fiscal year (FY) 2010 payroll data for each park.

Visitor spending impacts are estimated for all park units with visitation data. Payroll impacts are estimated for all parks including administrative units and parks without visit count data. Impacts measure the direct and secondary effects of visitor spending and park payrolls in terms of jobs, income, and value added.[2] Direct effects cover businesses selling goods and services directly to park visitors. Secondary effects include indirect effects resulting from sales to backward-linked industries within the local region and induced effects from household spending of income earned directly or indirectly from visitor spending. Impacts of construction activity and park purchases of goods and services are not included.

Impacts are estimated at both the national and local level. Most spending directly associated with park visits occurs in gateway regions around each park. Impacts of this spending on the local economies are estimated using local input-output models for each park. Local regions are defined as a 60-mile radius[3] around each park. To estimate impacts on the national economy, spending within roughly 60 miles of the park is applied to the national input-output model. System-wide totals covering impacts on local economies are also estimated by summing the spending and local impact estimates for all park units. Results for individual park units are reported in the Appendix.

# 2010 Updates

The 2010 estimates reflect new visitor surveys at seven parks. In 2010 visitor surveys were conducted at Delaware Water Gap NRA, Fort Union NM, Fossil Butte NM, George Washington Carver NM, New Bedford Whaling NHP, Rocky Mt. NP, and Wind Cave NP .[4] Spending and visitor profiles for these parks were updated based upon the survey data. For other parks, spending profiles from 2009 were price adjusted to 2010 using Bureau of Labor Statistics consumer price indices for each spending category. Consumer prices remained fairly stable

[2] Jobs include full-time and part-time jobs. Seasonal positions are adjusted to an annual basis. Labor income covers wages and salaries, including income of sole proprietors and payroll benefits. Value added is the sum of labor income, profits and rents, and indirect business taxes. It can also be defined as total sales net of the costs of all non-labor inputs. Value added is the preferred economic measure of the contribution of an industry or activity to the economy.

[3] The 60-mile radius is a general average representing the primary impact region around most parks. The radius is closer to 30 miles for parks in urban settings and as large as 100 miles for some western parks. Economic multipliers are based on regions defined as groupings of counties to approximate a 60-mile radius of the park.

[4] These studies are conducted by the Visitor Services Project (VSP) at the University of Idaho. Reports for individual parks are available at their website: http://www.psu.uidaho.edu/vsp.reports.htm

between 2009 and 2010 except for an increase of 18% in gas prices and an 8% increase in transportation costs.

Visitor segment mixes were assumed to be unchanged except as reflected in overnight stays or new visitor surveys. Except for parks with new visitor surveys, average party sizes, lengths of stay and re-entry factors were assumed to be unchanged from 2009. Visit and overnight stay figures for all parks were updated to 2010 from the NPS public use statistics (Street 2011).

Multipliers for individual parks were estimated last year based on 2008 IMPLAN data and IMPLAN's trade flow models (Stynes, 2010). Local regions were defined to include all counties within roughly 60 road miles of each park. For 2010, local region multipliers were adjusted from 2008 to 2009 based on structural changes in the national economy (i.e., ratios of jobs, income and value added to sales in each sector). Secondary effects and direct job ratios were adjusted to 2010 based on consumer price indices.

## Recreation Visits

The National Park System received 281.3 million recreation visits in 2010. Visitor spending was estimated by dividing visitors to each park into segments with distinct spending patterns and applying spending averages based on surveys of park visitors at selected parks. As spending averages are measured on a party day basis (party nights for overnight trips), the NPS counts of recreation visits are converted from person entries to a park to party days in the area by applying average party size, length of stay, and park re-entry factors. This adjusts for some double counting of visits. To the extent possible, spending not directly related to a park visit is excluded.[5]

In 2010 there were 14.58 million recreation overnight stays in the parks, representing 3.3% of all visits. Twenty-nine percent of park visits were day trips by local residents, 40% were day trips from 60 miles or more,[6] and 31% involved an overnight stay near the park. Visitor spending depends on the number of days spent in the local area and also the type of lodging on overnight trips. Non-local day trips account for 34% of the party days spent in the local area, local day trips 28%, and overnight stays 38%. Sixty-four percent of all overnight stays by park visitors are in motels, lodges, or bed and breakfasts outside the park; another 18% are in campgrounds outside the park, 6% in private homes; and 12% are inside the park in NPS campgrounds, lodges, or backcountry sites.

## Visitor Spending

Visitor spending averages cover expenses within the local region, excluding park entry fees. Spending averages for each segment are derived from park visitor surveys at selected parks over

[5] For example, spending during extended stays in an area visiting relatives, on business, or when the park visit was not the primary trip purpose is excluded. For most historic sites and parks in urban areas, spending for one day or night is counted for each park entry. Where several park units are within a 60-mile radius, adjustments are made for those visiting more than one park on the same day.

[6] Day trips include pass-thru visitors not spending a night within 60 miles of the park as well as stays with friends and relatives and in owned seasonal homes.

the past ten years. Bureau of Labor Statistics price indices for each spending category are applied to adjust all spending to 2010 dollars.

NPS System-wide spending averages for 2010 are given in Table 1 for seven distinct visitor segments. A typical park visitor party on a day trip spends $40 if a local resident and $70 if non-local (Table 1).

**Table 1**. National Park Visitor Spending in the Local Area by Segment, 2010 ($ per party per day/night)

| | Visitor Segment | | | | | | |
|---|---|---|---|---|---|---|---|
| **Spending category** | **Local Day Trip** | **Non-local Day Trip** | **NPS Lodge** | **NPS Camp Ground** | **Back-country** | **Motel-Outside Park** | **Camp-Outside Park** |
| Motel, hotel, B&B | 0.00 | 0.02 | 157.57 | 0.83 | 3.02 | 104.82 | 0.16 |
| Camping fees | 0.00 | 0.00 | 1.24 | 18.09 | 1.99 | 0.24 | 25.33 |
| Restaurants & bars | 12.61 | 19.37 | 73.42 | 13.86 | 7.35 | 62.45 | 16.56 |
| Amusements | 4.56 | 9.25 | 29.11 | 9.99 | 5.75 | 20.62 | 15.21 |
| Groceries | 6.08 | 6.86 | 14.06 | 16.32 | 5.71 | 15.29 | 12.63 |
| Gas & oil | 8.75 | 18.97 | 22.27 | 24.59 | 12.73 | 22.60 | 23.82 |
| Local transportation | 0.55 | 1.97 | 14.11 | 4.42 | 1.20 | 9.19 | 2.12 |
| Retail Purchases | 7.80 | 13.16 | 28.78 | 13.27 | 8.94 | 27.21 | 19.69 |
| **Total** | 40.36 | 69.60 | 340.55 | 101.39 | 46.69 | 262.41 | 115.51 |

Note – Columns may not sum to totals due to rounding.

On a party night basis, spending by visitors on overnight trips varies from $47 for backcountry campers to $341 for visitors staying in park lodges. Campers spend $116 per night if staying outside the park and $101 if staying inside the park. Spending averages at individual parks vary from these system-wide averages due to differences in local prices and spending opportunities. For example, while non-local visitors on day trips spent $39 per party at Badlands NP in 2010, their counterparts at Grand Canyon spent $146.

In total, park visitors spent $12.13 billion in the local region surrounding the parks in 2010.[7] Local residents account for 9.8% of this spending (Table 2). Visitors staying in motels and lodges outside the park account for 56% of the total spending while non-local visitors on day trips contribute 20% of all spending.

Lodging and restaurant/bar expenses each account for about a quarter of the spending. Transportation expenses (mainly auto fuel) account for 19%, groceries 8%, other retail purchases 13%, and recreation and entertainment 10% (Figure 1).

[7] Spending figures exclude airfares and other trip spending beyond 60 miles of the park. Purchases of durable goods (boats, RVs) and major equipment are also excluded. Special expenses for commercial rafting trips, air overflights and other special activities are not fully captured for all parks.

**Table 2**. National Park Visitor Spending by Segment, 2010

| Segment | Total Spending ($ Millions) | Percent of Spending |
|---|---|---|
| Local Day Trip | 1,186 | 9.8% |
| Non-local Day Trip | 2,448 | 20.2% |
| Lodge/Cabin-In Park | 375 | 3.1% |
| Camp-In Park | 294 | 2.4% |
| Backcountry Campers | 32 | 0.3% |
| Motel-Outside Park | 6,742 | 55.6% |
| Camp-Outside Park | 815 | 6.7% |
| Other Overnight Visitors | 242 | 2.0% |
| **Total** | 12,134 | 100.0% |

a. Other overnight visitors include visitors staying overnight in the area but not incurring lodging costs.

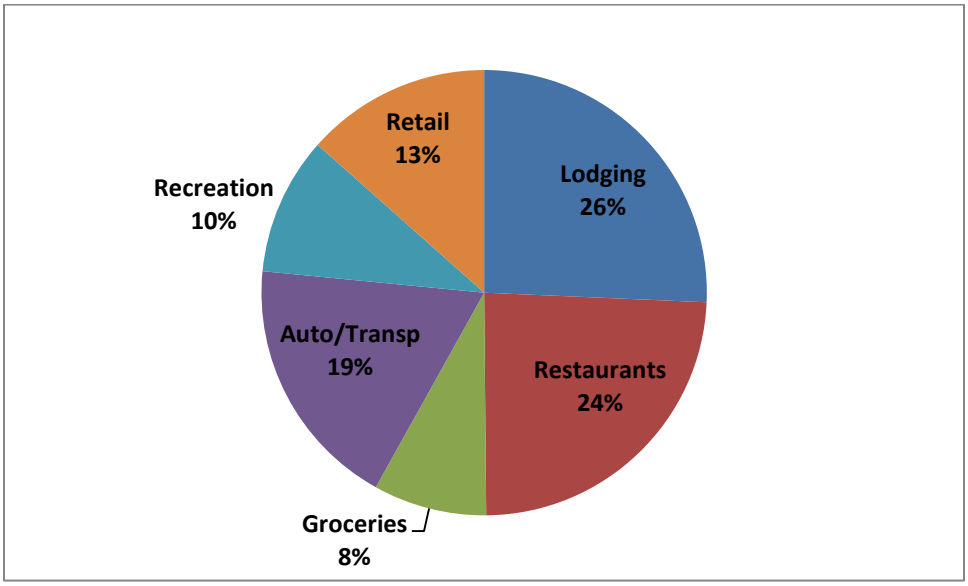



**Figure 1**. Distribution of National Park Visitor Spending

# Local Impacts of Visitor Spending

Local economic impacts of visitor spending are estimated in the MGM2 model using multipliers for local areas around each park. Multipliers capture both the direct and secondary economic effects in gateway communities around the parks in terms of jobs, labor income, and value added. National totals are calculated as the sum of the local impacts for 356 park units that have counts of visitors.

Both economic significance and economic impacts were estimated. The economic significance estimates in Table 3 measure the impacts of all visitor spending ($12.13 billion), including that of local visitors. Economic impacts in Table 4 exclude spending by local visitors, estimating the impacts of the $10.95 billion spent by visitors who do not reside within the local region.

**Table 3**. Economic Significance of National Park Visitor Spending to Local Economies, 2010

| Sector/Spending category | Sales ($ Millions) | Jobs | Labor Income ($ Millions) | Value Added ($ Millions) |
|---|---|---|---|---|
| Direct Effects | | | | |
| Motel, hotel cabin or B&B | 2,879 | 28,980 | 898 | 1,600 |
| Camping fees | 241 | 2,966 | 88 | 123 |
| Restaurants & bars | 2,931 | 49,136 | 1,110 | 1,563 |
| Amusements & Entertain. | 1,215 | 20,804 | 519 | 795 |
| Other vehicle expenses | 139 | 1,987 | 74 | 89 |
| Local transportation | 283 | 6,240 | 141 | 177 |
| Grocery stores | 253 | 4,395 | 132 | 214 |
| Gas stations | 405 | 5,875 | 207 | 338 |
| Other retail | 783 | 14,936 | 409 | 665 |
| Wholesale Trade | 291 | 1,569 | 111 | 191 |
| Local Manufacturing. | 266 | 460 | 27 | 54 |
| **Total Direct Effects** | **9,686** | **137,348** | **3,715** | **5,808** |
| Secondary Effects | 4,615 | 34,505 | 1,475 | 2,660 |
| **Total Effects** | **14,301** | **171,853** | **5,190** | **8,468** |

Notes: Economic significance covers all $12.13 billion in spending of park visitors in the local region, including that of local visitors. Jobs include full-time and part-time jobs with seasonal positions adjusted to an annual basis. Labor income covers wages and salaries, including income of sole proprietors and payroll benefits. Value added is the sum of labor income, profits and rents, and indirect business taxes. Columns may not sum to totals due to rounding.

**Table 4**. Economic Impacts of National Park Visitor Spending on Local Economies, 2010

| Sector/Spending category | Sales ($ Millions) | Jobs | Labor Income ($ Millions) | Value Added ($ Millions) |
|---|---|---|---|---|
| Direct Effects | | | | |
| Motel, hotel cabin or B&B | 2,879 | 28,980 | 898 | 1,600 |
| Camping fees | 241 | 2,966 | 88 | 123 |
| Restaurants & bars | 2,560 | 43,160 | 966 | 1,362 |
| Amusements & Entertain. | 1,081 | 18,559 | 461 | 705 |
| Other vehicle expenses | 125 | 1,804 | 66 | 80 |
| Local transportation | 280 | 6,174 | 140 | 175 |
| Grocery stores | 208 | 3,652 | 108 | 175 |
| Gas stations | 348 | 5,104 | 177 | 290 |
| Other retail | 673 | 12,892 | 352 | 572 |
| Wholesale Trade | 240 | 1,320 | 91 | 157 |
| Local Manufacturing | 200 | 351 | 20 | 40 |
| **Total Direct Effects** | **8,836** | **124,962** | **3,367** | **5,279** |
| Secondary Effects | 4,122 | 31,317 | 1,316 | 2,371 |
| **Total Effects** | **12,958** | **156,279** | **4,683** | **7,650** |

Note: Economic impacts cover the $10.95 billion spent by non-local visitors. Columns may not sum to totals due to rounding.

Economic impact measures attempt to estimate the likely losses in economic activity to the region in the absence of the park. Should the park opportunities not be available, it is assumed that local residents would spend the money on other local activities, while visitors from outside the region would not have made a trip to the region.[8] Spending by local residents on visits to the park do not represent "new money" to the region and are therefore generally excluded when estimating impacts. Local resident spending is included in the economic significance measures, as these capture all economic activity associated with park visits, including local and non-local visitors.

## Economic Significance

The $12.13 billion spent by park visitors within 60 miles of the park (Table 2) has a total economic effect (significance) of $14.30 billion in sales, $5.19 billion in labor income, and $8.47 billion in value added. Visitor spending supports about 171,850 jobs in gateway regions. Total effects may be divided between the direct effects that occur in businesses selling goods and services directly to park visitors and secondary effects that result from the circulation of this money within the local economy.[9]

Direct effects are $9.68 billion in sales, $3.71 billion in labor income, $5.81 billion in value added, and 137,350 jobs. The local region captures 80% of all visitor spending as direct sales. Note that direct sales of $9.68 billion is less than the $12.13 billion in visitor spending as most of the manufacturing share of retail purchases (groceries, gas, sporting goods, souvenirs) is not included. It is assumed that most of the producer price of retail purchases immediately leaks out of the region to cover the cost of goods sold. Sales figures for retail and wholesale trade are the margins on retail purchases.

The average sales multiplier across all local park regions is 1.47. For every dollar of direct sales another $ .47 in sales is generated in the local region through secondary effects.

## Economic Impacts

Excluding $1.19 billion dollars spent by local residents on park visits reduces the total spending to $10.95 billion (Table 2) for the impact analysis. Local visitors represent about 29% of all visits but less than 10% of all visitor spending. The total effects of visitor spending excluding locals is $12.96 billion in sales, $4.68 billion in labor income, $7.65 billion in value added, and 156,280 jobs. The economic sectors most directly affected are lodging, restaurants, retail trade, and amusements. Non-local visitor spending supports 43,160 jobs in restaurants and bars, 32,000 jobs in lodging sectors, 23,000 jobs in retail and wholesale trade, and 18,560 jobs in amusements.

[8] To the extent possible, spending not directly associated with a park visit is also excluded. For example, only one night's expenses are counted for visitors in the area primarily on business, visiting relatives, or visiting other attractions. For parks with visitor surveys, spending attributed to a park visit was estimated based on the percentage of visitors identifying the park visit as the primary purpose of the trip.

[9] Secondary effects include indirect effects of businesses buying goods and services from backward-linked local firms and induced effects of household spending of their earnings.

# National Economic Significance of NPS Visitor Spending

The contribution of NPS visitor spending to the national economy can be estimated by applying the spending totals to multipliers for the national economy. This circulates spending that occurs within gateway regions around national parks within the broader national economy, capturing impacts on sectors that manufacture goods purchased by park visitors and additional secondary effects.

The estimates do not include spending by park visitors at home for durable goods such as camping, hunting and fishing equipment, recreation vehicles, boats, and other goods used on trips to the national parks. The estimates also exclude airfares and other en route spending that occurs more than 60 miles from the park. Since many long-distance trips involve multiple purposes and often visits to multiple parks, it is difficult to capture these expenses without double counting or attributing spending not directly related to a national park visit.

With the above exclusions, the contribution of visitor spending to the national economy is 258,400 jobs, $9.81 billion in labor income, and $16.62 billion in value added (Table 5). With the exception of manufacturing activity and a portion of activity in wholesale trade, the direct effects of visitor spending accrue to local regions around national parks.[10]

Compared to the contribution to local economies (Table 4), an additional 88,200 jobs are supported nationally by NPS visitor spending, primarily due to the greater indirect and induced effects at the national level. The sales multiplier for NPS visitor spending at the national level is 2.65, compared to an average of 1.46 for local regions around national parks.

**Table 5**. Economic Significance of National Park Visitor Spending on National Economy, 2010

| Sector/Spending category | Sales ($ Millions) | Jobs | Labor Income ($ Millions) | Value Added ($ Millions) |
|---|---|---|---|---|
| Direct Effects | | | | |
| Motel, hotel, cabin or B&B | 2,879 | 29,253 | 909 | 1,588 |
| Camping fees | 241 | 2,949 | 93 | 127 |
| Restaurants & bars | 2,929 | 47,007 | 1,071 | 1,508 |
| Amusements & Entertain. | 1,214 | 21,323 | 534 | 810 |
| Other vehicle expenses | 139 | 1,901 | 71 | 86 |
| Local transportation | 283 | 6,217 | 141 | 177 |
| Grocery stores | 253 | 4,247 | 129 | 209 |
| Gas stations | 405 | 6,443 | 208 | 333 |
| Other retail | 783 | 14,432 | 402 | 658 |
| Wholesale Trade | 472 | 2,344 | 180 | 310 |
| Local Manufacturing | 2,137 | 3,609 | 222 | 506 |
| **Total Direct Effects** | **11,734** | **139,725** | **3,961** | **6,313** |
| Secondary Effects | 19,346 | 118,691 | 5,851 | 10,310 |
| **Total Effects** | **31,080** | **258,416** | **9,812** | **16,623** |

[10] Local economic ratios are therefore used to estimate the direct effects. National multipliers are used to estimate secondary effects. With the exception of wholesale trade and manufacturing sectors, the national direct effects (Table 5) are therefore the same as the local direct effects (Table 4).

## Impacts of NPS Payrolls

National park units also impact local and national economies through their own spending, especially NPS payrolls. Payroll impacts were estimated for FY 2010. In FY 2010 the National Park Service employed 26,031 people[11] with a total payroll of $1,709 million in wages, salaries, and payroll benefits (Table 6). Including the induced effects of the spending of NPS wages and salaries in the local region, the total local economic impact of park payrolls on local economies in 2010 was $1.95 billion in labor income, $2.16 billion in value added, and 32,407 jobs. Impacts on the U.S. economy were $2.41 billion in labor income, $2.96 billion in value added and 41,689 jobs.

**Table 6**. NPS Payroll Impacts on Local and National Economies, 2010

| | Jobs | Labor Income ($ Millions) | Value Added ($ Millions) |
|---|---|---|---|
| NPS Payroll | 26,031 | 1,709 | 1,709 |
| **Local Impacts** | | | |
| Induced effects | 6,376 | 242 | 456 |
| Total Local Impacts | 32,407 | 1,950 | 2,164 |
| **National Impacts** | | | |
| Induced Effects | 15,658 | 704 | 1,250 |
| Total National Impacts | 41,689 | 2,413 | 2,959 |

Note: Columns may not sum to totals due to rounding.

Impacts of park payrolls for each park unit were estimated by applying economic multipliers to wage and salary data to capture the induced effects of NPS employee spending on local economies. The overall local employment multiplier for NPS jobs is 1.25. For every four NPS jobs, another local job is supported through the induced effects of employee spending in the local region. The national employment multiplier is 1.60, due to a greater number of secondary jobs when we allow spending to circulate beyond the local region. There are additional local and national economic effects from NPS purchases of goods and services and from construction activity. These impacts were not estimated.

The visitor spending and payroll impacts may be combined, as park admission fees and most other visitor spending accruing to the National Park Service were omitted from the visitor spending figures to avoid double counting.[12] Using the visitor spending impact estimates from Table 4, which exclude spending of local visitors, the combined total impacts including secondary effects are $6.63 billion in labor income, $9.81 billion in value added, and 188,686 local jobs. Visitor spending accounts for 83% of the total jobs and 78% of the total value added (Table 7).

[11] The number of employees is estimated as an annual average for each park, so that seasonal positions are converted to annual equivalents. However, the job estimates include both full-time and part-time positions.

[12] There will be some double counting of camping fees as payments to concessionaires could not be fully sorted out from payments to the National Park Service.

**Table 7**. Combined Impacts on Local Economies –Visitor Spending and Payroll

| Impact Measure | Visitor Spending Impacts[a] | NPS Payroll Impacts | Combined Impacts | Visitor Spending Share |
|---|---|---|---|---|
| Direct Effects | | | | |
| Jobs | 124,962 | 26,031 | 150,993 | 83% |
| Labor Income ($ Millions) | 3,367 | 1,709 | 5,076 | 66% |
| Value Added ($ Millions) | 5,279 | 1,709 | 6,988 | 76% |
| Total Effects | | | | |
| Jobs | 156,279 | 32,407 | 188,686 | 83% |
| Labor Income ($ Millions) | 4,683 | 1,950 | 6,634 | 71% |
| Value Added ($ Millions) | 7,650 | 2,164 | 9,815 | 78% |

[a] Excludes spending by local visitors

**Table 8.** Combined Impacts on National Economy–Visitor Spending and Payroll

| Impact Measure | Visitor Spending Impacts[a] | NPS Payroll Impacts | Combined Impacts | Visitor Spending Share |
|---|---|---|---|---|
| Direct Effects | | | | |
| Jobs | 139,725 | 26,031 | 165,756 | 84% |
| Labor Income ($ Millions) | 3,961 | 1,709 | 5,670 | 70% |
| Value Added ($ Millions) | 6,313 | 1,709 | 8,022 | 79% |
| Total Effects | | | | |
| Jobs | 258,416 | 41,689 | 300,104 | 86% |
| Labor Income ($ Millions) | 9,812 | 2,413 | 12,225 | 80% |
| Value Added ($ Millions) | 16,623 | 2,959 | 19,582 | 85% |

## State-by-State Impact Estimates

Economic impacts of individual parks can be aggregated to the state level with a few complications. While most parks fall within a single state, there are 20 park units with facilities in more than one state. For these parks, shares of visits were assigned to each state based on percentages provided by the NPS Public Use Statistics Office. It was assumed that spending and economic impacts are proportional to where recreation visits are assigned.

Estimates of recreation visits, spending, and local economic impacts for each state and U.S. territory are given in Table A-4 in the Appendix. States receiving the greatest economic effects from NPS visitor and payroll spending are California; Washington, D.C.; Arizona; North Carolina; Utah; and Wyoming. Regional totals are given in Table A-5.

It should be noted that the state and regional totals represent an accumulation of local impacts within roughly 60 miles of each park. The total economic effects on each state or region would

be much larger if we included all spending of NPS visitors within each state and used statewide multipliers instead of local ones to capture the secondary effects. As noted earlier, impacts reported here do not include long-distance travel, airfares, or purchases made at home for items that may be used on trips to national parks.

## Methods

Spending and impacts were estimated using the MGM2 model. NPS public use statistics for calendar year 2010 provide estimates of the number of recreation visits and overnight stays at each park. For each park, recreation visits were allocated to the seven MGM2 segments,[13] converted to party days/nights spent in the local area and then multiplied by per-day spending averages for each segment. Spending and impact estimates for 2010 are made individually for each park unit and then summed to obtain national totals for impacts on local regions. Impacts on the national economy are also estimated by applying all visitor spending to multipliers for the national economy.

Spending averages cover all trip expenses within roughly 60 miles of the park. They therefore exclude most en route expenses on longer trips, as well as airfares and purchases made at home in preparation for the trip, including costs of durable goods and equipment. Spending averages vary from park to park based on the type of park and the regional setting (low, medium, or high spending area).

The segment mix is very important in estimating visitor spending, as spending varies considerably across the MGM2 segments. Segment shares are estimated based on park overnight stay data and, where available, park visitor surveys. For park units that lack recent visitor surveys, estimates are made by generalizing from studies at similar parks or based on manager or researcher judgment.

For parks with VSP (Visitor Services Project) studies over the past ten years, spending averages are estimated from the visitor survey data at each park.[14] Averages estimated in the surveys were price adjusted to 2010 using BLS price indices for each spending category. Sampling errors for the spending averages in VSP studies are generally 5–10% overall and can be as high as 20% for individual visitor segments.

The observed spending patterns in park visitor studies are then used to estimate spending averages for other parks that lack visitor spending surveys. This procedure will not capture some spending variations attributable to unique characteristics of a given park or gateway region—for example, the wider use of public transportation at Alaska parks or extra expenses for special commercial attractions in or around some parks, such as rafting trips, air overflights, and other

[13] Visits are classified as local day trips, non-local day trips, and overnight trips staying in campgrounds or hotels, lodges, cabins, and bed and breakfasts. For parks with lodging facilities within the park, visitors staying in park lodges, campgrounds, or backcountry sites are distinguished from those staying outside the park in motels or non-NPS campgrounds. Visitors staying with friends or relatives, in owned seasonal homes, or passing through without a local overnight stay are generally treated as day trips.

[14] Detailed impact reports for parks that have included economic questions in their VSP studies are available at the MGM2 (http://web4.canr.msu.edu/mgm2/) or NPS social science websites (http://www.nature.nps.gov/socialscience/products.cfm#MGM2Reports).

tours. When visitor studies are conducted at individual parks, these unique situations are taken into account.

Multipliers for local regions around national parks were applied to the spending totals to translate spending into jobs, income, and value added and also to estimate secondary effects. All MGM2 multipliers were re-estimated last year using IMPLAN ver 3.0 and 2008 economic data (Minnesota IMPLAN Group 2009). The multipliers have been adjusted to 2010 based on structural changes in the national IMPLAN models between 2008 and 2009 and price changes between 2009 and 2010.

Based on national IMPLAN models, there were some significant structural changes in economic ratios and multipliers between 2008 and 2009. Most notable, was a change in ratios for the amusements sector (IMPLAN sector 410) due to an inflated estimate of output in 2008. IMPLAN ratios in 2009 for sector 410 were more than double the 2008 estimates. This caused a significant underestimate of jobs, income and value added in the MGM2 amusements sector estimates last year. In addition, there were increases of 15-30% in the ratios for retail trade sectors between 2008 and 2009. Ratios for the hotel sector (IMPLAN sector 411) declined by roughly 10%. The MGM2 estimates of jobs, income and value added are sensitive to any changes in these ratios and multipliers.

With the exception of parks with new visitor surveys in 2010, no changes were made in party sizes, lengths of stay, or re-entry factors between 2009 and 2010. MGM2 model parameters for individual parks are adjusted over time as new park visitor studies are conducted or other relevant information becomes available.

Impacts of park payrolls were estimated for each park by applying local area multipliers to NPS wage and salary figures for FY 2010. Multipliers capture the induced effects of park employee spending by re-circulating their income as household spending within the local economy. Payroll benefits (e.g. contributions to retirement and health insurance) were not re-circulated in estimating secondary effects of park employee spending, but the direct payroll benefits are included in total value added. Multipliers for IMPLAN sector 439 (federal government payroll) were applied to wages and salaries at each park to estimate induced effects.[15] Local impacts of park purchases of supplies and services or construction activities were not included in the analysis.

The number of employees for each park was estimated by totaling the number of distinct social security numbers in each pay period and dividing by the number of pay periods. The figure is therefore an annual average. Four seasonal jobs for three months count as one job. No distinction is made between part-time and full-time employees. Jobs, salary, and payroll benefits are assigned to the park where the employee's time was charged, which may differ from their duty station.

Spending and impact totals for states were developed from the 2010 estimates by summing the results for all units in a given state using the mailing address for the park to identify the state. Twenty parks have facilities in more than one state. For these parks, visitors and spending were

[15] Multipliers were adjusted by a factor of 1.1359 to account for the share of federal payroll that IMPLAN assigns to capital depreciation.

allocated to individual states based on shares used by the NPS Public Use Statistics Office for allocating visits to states. For example, visits to Great Smoky Mountains NP were split 44% to North Carolina and 56% to Tennessee. It should be noted that these allocations may not fully account for where the spending and impacts occur. There are also many other parks with facilities in a single state but located within 60 miles of a state border. A portion of the spending and impacts for these parks may accrue to nearby states.

## Errors and Limitations

The accuracy of the spending and impact estimates rests largely on the input data, namely (1) public use recreation visit and overnight stay data; (2) party size, length of stay, and park re-entry conversion factors; (3) visitor segment shares; (4) spending averages; and (5) local area multipliers.

Public use data provides reasonably accurate estimates of visitor entries for most parks. Some visitors may be missed by the counting procedures, while others may be counted multiple times when they re-enter a park more than once on a single trip. Accurate estimates of park re-entries, party sizes, and lengths of stay in the area are needed to convert park entries to the number of visitor or party days in the region. Visitors staying overnight outside the park pose significant problems as they tend to be the greatest spenders and may enter the park several times during their stay. Similarly, visitors staying inside the park may enter and leave several times during their stay and be counted each time as a distinct visit. Re-entry factors adjust for these problems to the extent possible.

For multi-purpose trips, it is difficult to determine what portion of the spending should be attributed to the park visit. This is especially a problem for historic sites and parks in urban areas or parks in multiple-attraction destinations. For parks with visitor surveys, the proportion of days and spending counted was decided based on stated trip purposes and the importance of the park in generating the trip to the region.

Parkways and urban parks pose special difficulties for economic impact analyses. These units have some of the highest number of visits while posing the most difficult problems for estimating visits, spending, and impacts. The majority of visits to these types of units were assumed to be local or non-local day trips, and only one night of spending was counted for overnight trips. Due to the high numbers of visits at these units, small changes in assumed spending averages or segment mixes can swing the spending estimates by substantial amounts.

Clusters of parks within a single 60-mile area pose additional difficulties. For example, the many monuments and parks in the Washington, D.C., area each count visitors separately. Similar difficulties exist for clusters of parks in Boston, New York, and San Francisco. To avoid double counting of spending across many national capital parks, we must know how many times a visitor has been counted at park units during a trip to the Washington, D.C., area. For parks in the National Capital Region, we currently assume an average of 1.7 park visits are counted for local day trips, 3.4 visits for non-local day trips, and 5.1 park visits on overnight trips. The non-local visitor spending total for the National Capital Region in 2010 was $1.17 billion. This is 14% of the Travel Industry Association tourist spending estimate of $8.3 billion for Washington, D.C., in 2008 (USTA 2010).

NPS units in Alaska also pose special problems for economic analysis. Spending opportunities near Alaska parks are limited and for many visitors the park visit is part of a cruise or guided tour, frequently purchased as a package. Most visitors are on extended trips to Alaska, making it difficult to allocate expenses to a particular park visit. Lodging, vehicle rentals, and air expenses frequently occur in Anchorage, many miles from the park. Also, many Alaska parks are only accessible by air or boat, so spending profiles estimated from visitor surveys at parks in the lower 48 states do not apply well. Due to the prominence of cruise lines and package tours, special studies are required to estimate the proportion of visitor spending that stays in the local regions around national park units in Alaska. In this report, Alaska statewide multipliers are used to estimate impacts for parks in Alaska.

A visit to one or more national parks is an important part of the trip for most Alaska visitors. One could therefore argue to count a substantial portion of tourism spending in Alaska as related to national park visits. The U.S. Travel Association estimated tourist spending in Alaska at $2.1 billion in 2008 (USTA 2010). This is ten times what we have included as spending by park visitors in the local regions around Alaska national parks. Including spending in Alaska outside the local regions would significantly increase the estimates; however, deciding which spending to include would be somewhat subjective.

## References

Minnesota IMPLAN Group Inc. 2009. IMPLAN Pro Version 3.0, user's guide. Stillwater, Minnesota.

Street, B. 2011. Statistical abstract: 2010. Natural Resource Data Series NPS/NRPC/SSD/NRDS—2011/147. National Park Service, Fort Collins, Colorado.

Stynes, D.J. 2010. Economic benefits to local communities from national park visitation and payroll, 2009. Natural Resources Report NPS/NRPC/SSD/NRR –2010/281. National Park Service, Fort Collins, Colorado.

Stynes, D. J., D. B. Propst, W. H. Chang, and Y. Sun. 2000. Estimating regional economic impacts of park visitor spending: Money Generation Model Version 2 (MGM2). Department of Park, Recreation and Tourism Resources, Michigan State University, East Lansing, Michigan.

U.S. Travel Association (USTA). 2010. The power of travel, economic impact of travel and tourism. Available at http://www.poweroftravel.org/statistics/.

## Appendices

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010....…….18

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010……..... .. 27

**Table A-3**. Payroll Impacts of National Park Units on Local Economies, Administrative Units and Parks without Visit Counts, FY 2010……...35

**Table A-4**. Impacts of NPS Visitor Spending and Payroll on Local Economies by State, 2010…….……38

**Table A-5**. Impacts of NPS Visitor Spending and Payroll on Local Economies by Region, 2010……40

**Table A-6**. Allocations to States for Multi-state Parks…….. .. 41

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010

| | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| **Park Unit** | **2010 Recreation Visits** | **2010 Overnight Stays** | **All Visitors ($000's)** | **Non-Local Visitors ($000's)** | **Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Abraham Lincoln Birthplace NHP | 177,122 | 0 | 6,167 | 5,740 | 97 | 2,720 | 4,436 |
| Acadia NP | 2,504,208 | 159,631 | 186,282 | 183,491 | 3,147 | 79,636 | 130,084 |
| Adams NHP | 73,339 | 0 | 4,742 | 4,414 | 66 | 2,581 | 4,199 |
| Agate Fossil Beds NM | 12,509 | 0 | 760 | 754 | 13 | 276 | 445 |
| Alibates Flint Quarries NM | 4,350 | 0 | 216 | 201 | 3 | 68 | 105 |
| Allegheny Portage Railroad NHS | 107,363 | 0 | 5,340 | 4,971 | 82 | 2,033 | 3,280 |
| Amistad NRA | 1,574,322 | 27,781 | 45,348 | 39,475 | 615 | 12,711 | 20,656 |
| Andersonville NHS | 121,535 | 0 | 4,232 | 3,939 | 68 | 1,600 | 2,609 |
| Andrew Johnson NHS | 60,323 | 0 | 3,001 | 2,793 | 45 | 1,249 | 2,044 |
| Antietam NB | 393,957 | 0 | 19,347 | 17,429 | 250 | 9,493 | 15,663 |
| *Apostle Islands NL | 156,945 | 24,358 | 17,281 | 16,920 | 287 | 6,359 | 10,008 |
| Appomattox Court House NHP | 216,220 | 0 | 10,755 | 10,010 | 158 | 3,925 | 6,469 |
| *Arches NP | 1,014,405 | 47,112 | 105,132 | 105,132 | 1,659 | 37,449 | 60,742 |
| Arkansas Post NMEM | 34,712 | 0 | 1,209 | 1,125 | 20 | 369 | 607 |
| Arlington House, Robert E. Lee MEM | 627,576 | 0 | 40,581 | 37,771 | 450 | 18,670 | 30,129 |
| Assateague Island NS | 2,106,090 | 82,461 | 142,650 | 135,543 | 2,041 | 59,120 | 97,895 |
| Aztec Ruins NM | 37,437 | 0 | 1,172 | 1,135 | 16 | 435 | 716 |
| *Badlands NP | 977,778 | 36,506 | 23,177 | 23,177 | 375 | 9,189 | 14,990 |
| Bandelier NM | 234,896 | 7,263 | 10,507 | 10,152 | 121 | 2,789 | 4,434 |
| Bent's Old Fort NHS | 29,120 | 0 | 1,014 | 944 | 14 | 306 | 497 |
| Bering Land Bridge NPRES | 2,642 | 1,123 | 833 | 833 | 9 | 322 | 554 |
| Big Bend NP | 372,330 | 175,574 | 16,121 | 15,423 | 231 | 5,336 | 8,969 |
| Big Cypress NPRES | 665,523 | 16,418 | 78,758 | 77,146 | 1,149 | 41,721 | 67,505 |
| Big Hole NB | 44,771 | 0 | 1,559 | 1,451 | 25 | 541 | 895 |
| Big South Fork NRRA | 656,374 | 65,160 | 26,575 | 23,218 | 331 | 7,797 | 12,567 |
| Big Thicket NPRES | 140,489 | 1,932 | 9,521 | 9,040 | 132 | 4,466 | 7,682 |
| Bighorn Canyon NRA | 258,637 | 20,577 | 7,567 | 6,630 | 106 | 2,723 | 4,518 |
| Biscayne NP | 467,612 | 12,702 | 30,721 | 30,358 | 407 | 14,543 | 23,786 |
| Black Canyon of the Gunnison NP | 176,344 | 16,400 | 8,334 | 7,929 | 112 | 2,781 | 4,610 |
| Blue Ridge Parkway | 14,517,118 | 150,520 | 299,787 | 274,134 | 4,008 | 87,995 | 142,233 |
| Bluestone NSR | 37,790 | 0 | 1,610 | 1,407 | 18 | 359 | 562 |
| Booker T. Washington NM | 21,665 | 0 | 1,078 | 1,003 | 17 | 422 | 691 |
| Boston African American NHS | 333,463 | 0 | 21,563 | 20,070 | 259 | 10,889 | 17,560 |
| Boston NHP | 2,060,497 | 0 | 72,023 | 69,624 | 904 | 38,412 | 62,525 |
| Brown V. Board of Education NHS | 17,808 | 0 | 886 | 824 | 14 | 409 | 698 |
| Bryce Canyon NP | 1,285,492 | 146,965 | 107,904 | 106,864 | 1,667 | 34,869 | 57,707 |
| Buck Island Reef NM | 27,403 | 3,920 | 1,846 | 1,758 | 27 | 591 | 965 |
| Buffalo National River | 1,545,599 | 114,898 | 47,169 | 41,554 | 594 | 14,794 | 24,310 |
| Cabrillo NM | 763,140 | 0 | 49,347 | 45,930 | 613 | 21,142 | 34,738 |
| Canaveral NS | 966,099 | 2,702 | 65,558 | 62,234 | 990 | 32,397 | 53,679 |

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010 (continued)

| | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| **Park Unit** | **2010 Recreation Visits** | **2010 Overnight Stays** | **All Visitors ($000's)** | **Non-Local Visitors ($000's)** | **Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Cane River Creole NHP | 25,115 | 0 | 1,249 | 1,163 | 19 | 435 | 701 |
| Canyon de Chelly NM | 827,247 | 50,502 | 40,641 | 37,879 | 537 | 12,832 | 21,022 |
| Canyonlands NP | 435,908 | 88,191 | 34,633 | 34,291 | 474 | 12,713 | 21,154 |
| Cape Cod NS | 4,653,706 | 22,725 | 171,182 | 136,191 | 1,856 | 66,005 | 108,739 |
| Cape Hatteras NS | 2,193,292 | 84,393 | 108,475 | 103,084 | 1,615 | 42,057 | 69,452 |
| Cape Krusenstern NM | 2,521 | 427 | 794 | 794 | 9 | 304 | 520 |
| Cape Lookout NS | 530,181 | 29,268 | 37,276 | 35,501 | 572 | 12,749 | 20,852 |
| Capitol Reef NP | 662,661 | 38,566 | 37,958 | 37,740 | 649 | 13,025 | 21,439 |
| *Capulin Volcano NM | 48,580 | 0 | 1,341 | 1,316 | 18 | 360 | 590 |
| Carl Sandburg Home NHS | 86,740 | 0 | 4,315 | 4,016 | 61 | 1,593 | 2,581 |
| Carlsbad Caverns NP | 428,524 | 170 | 23,328 | 22,744 | 346 | 7,225 | 11,843 |
| Casa Grande Ruins NM | 77,347 | 0 | 2,259 | 2,121 | 23 | 585 | 903 |
| Castillo de San Marcos NM | 708,549 | 0 | 45,817 | 42,644 | 581 | 17,342 | 28,697 |
| Castle Clinton NM | 4,126,378 | 0 | 77,409 | 53,845 | 619 | 27,171 | 44,063 |
| Catoctin Mountain Park | 385,745 | 33,134 | 19,576 | 18,299 | 217 | 9,022 | 14,477 |
| Cedar Breaks NM | 525,831 | 0 | 18,309 | 17,041 | 274 | 6,674 | 10,962 |
| Chaco Culture NHP | 34,226 | 9,829 | 925 | 891 | 12 | 282 | 459 |
| Chamizal NMEM | 226,535 | 0 | 14,649 | 13,634 | 232 | 5,659 | 9,536 |
| Channel Islands NP | 277,515 | 59,584 | 24,004 | 22,881 | 300 | 11,357 | 18,568 |
| Charles Pinckney NHS | 44,081 | 0 | 2,193 | 2,041 | 32 | 901 | 1,505 |
| Chattahoochee River NRA | 3,011,393 | 0 | 89,784 | 60,449 | 780 | 28,133 | 46,090 |
| *Chesapeake & Ohio Canal NHP | 4,111,238 | 10,231 | 53,103 | 33,842 | 453 | 18,184 | 29,230 |
| Chickamauga & Chattanooga NMP | 991,901 | 2,204 | 49,364 | 45,951 | 724 | 21,928 | 36,116 |
| Chickasaw NRA | 1,253,637 | 66,127 | 17,157 | 13,276 | 174 | 3,798 | 6,200 |
| Chiricahua NM | 55,436 | 8,521 | 2,859 | 2,681 | 35 | 900 | 1,453 |
| Christiansted NHS | 117,214 | 0 | 4,081 | 3,799 | 58 | 1,269 | 2,071 |
| City of Rocks NRES | 92,484 | 0 | 6,278 | 5,959 | 85 | 2,078 | 3,361 |
| Clara Barton NHS | 23,741 | 0 | 1,535 | 1,429 | 17 | 706 | 1,140 |
| *Colonial NHP | 3,459,965 | 0 | 60,693 | 55,798 | 913 | 23,734 | 39,897 |
| Colorado NM | 433,561 | 17,300 | 21,766 | 20,299 | 292 | 7,596 | 12,389 |
| Congaree NP | 121,208 | 4,981 | 2,788 | 2,466 | 44 | 1,132 | 1,877 |
| Coronado NMEM | 136,284 | 0 | 4,745 | 4,417 | 63 | 1,779 | 2,910 |
| Cowpens NB | 226,868 | 17 | 11,284 | 10,503 | 180 | 4,770 | 7,901 |
| *Crater Lake NP | 448,319 | 80,467 | 34,111 | 33,088 | 540 | 13,393 | 21,887 |
| *Craters of the Moon NM & PRES | 215,698 | 14,856 | 6,732 | 6,660 | 95 | 2,117 | 3,440 |
| Cumberland Gap NHP | 918,746 | 15,917 | 45,833 | 42,693 | 695 | 14,723 | 23,831 |
| Cumberland Island NS | 91,996 | 17,979 | 6,156 | 5,869 | 92 | 2,922 | 4,826 |
| Curecanti NRA | 969,549 | 54,667 | 40,364 | 35,295 | 478 | 11,899 | 19,545 |
| Cuyahoga Valley NP | 2,492,670 | 2,719 | 54,677 | 39,446 | 599 | 17,681 | 28,912 |
| *Dayton Aviation Heritage NHP | 63,961 | 0 | 3,268 | 3,092 | 57 | 1,472 | 2,407 |
| De Soto NMEM | 265,406 | 0 | 17,162 | 15,974 | 268 | 8,622 | 14,247 |

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010 (continued)

| | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| **Park Unit** | **2010 Recreation Visits** | **2010 Overnight Stays** | **All Visitors ($000's)** | **Non-Local Visitors ($000's)** | **Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Death Valley NP | 984,775 | 221,614 | 48,620 | 46,529 | 517 | 13,733 | 21,544 |
| Delaware Water Gap NRA | 5,285,761 | 104,558 | 151,261 | 129,257 | 2,087 | 57,652 | 93,307 |
| *Denali NP & PRES | 378,855 | 106,108 | 141,415 | 141,415 | 1,822 | 56,211 | 83,330 |
| Devils Postpile NM | 80,349 | 4,444 | 2,835 | 2,646 | 38 | 1,081 | 1,749 |
| Devils Tower NM | 436,200 | 15,939 | 15,321 | 14,286 | 229 | 5,643 | 9,295 |
| Dinosaur NM | 197,812 | 49,659 | 6,717 | 6,291 | 77 | 2,203 | 3,655 |
| Dry Tortugas NP | 53,890 | 13,786 | 4,689 | 4,480 | 52 | 1,899 | 3,147 |
| Edgar Allan Poe NHS | 16,584 | 0 | 1,072 | 998 | 15 | 554 | 910 |
| *Effigy Mounds NM | 79,783 | 0 | 4,625 | 4,431 | 80 | 1,513 | 2,442 |
| *Eisenhower NHS | 61,210 | 0 | 3,845 | 3,814 | 64 | 1,461 | 2,368 |
| El Malpais NM | 134,662 | 680 | 4,924 | 4,742 | 79 | 2,133 | 3,513 |
| El Morro NM | 52,566 | 2,525 | 1,834 | 1,756 | 25 | 536 | 889 |
| Eleanor Roosevelt NHS | 53,067 | 0 | 907 | 561 | 8 | 232 | 377 |
| Eugene O'Neill NHS | 2,445 | 0 | 158 | 147 | 2 | 82 | 137 |
| *Everglades NP | 915,538 | 33,110 | 136,494 | 131,383 | 1,956 | 72,196 | 117,401 |
| Federal Hall NMEM | 178,749 | 0 | 11,559 | 10,758 | 124 | 6,016 | 9,808 |
| Fire Island NS | 613,057 | 43,656 | 35,076 | 30,753 | 390 | 15,827 | 25,886 |
| First Ladies NHS | 8,766 | 0 | 567 | 528 | 9 | 205 | 332 |
| Flight 93 NMEM | 137,837 | 0 | 6,856 | 6,381 | 102 | 2,465 | 3,976 |
| Florissant Fossil Beds NM | 65,422 | 0 | 3,254 | 3,029 | 41 | 1,230 | 2,025 |
| Ford's Theatre NHS | 662,298 | 0 | 21,476 | 19,661 | 234 | 9,930 | 16,277 |
| Fort Bowie NHS | 9,491 | 0 | 472 | 439 | 6 | 150 | 243 |
| Fort Caroline NMEM | 299,906 | 0 | 19,393 | 18,050 | 283 | 8,997 | 14,846 |
| Fort Davis NHS | 43,280 | 0 | 1,507 | 1,403 | 21 | 454 | 752 |
| Fort Donelson NB | 202,210 | 32 | 7,041 | 6,553 | 105 | 2,241 | 3,661 |
| Fort Frederica NM | 294,484 | 0 | 14,648 | 13,634 | 201 | 5,524 | 9,044 |
| Fort Laramie NHS | 57,128 | 0 | 1,989 | 1,851 | 29 | 673 | 1,119 |
| *Fort Larned NHS | 29,423 | 0 | 1,598 | 1,563 | 28 | 560 | 916 |
| Fort Matanzas NM | 673,700 | 0 | 43,564 | 40,547 | 552 | 16,489 | 27,286 |
| Fort McHenry NM & HS | 611,582 | 0 | 39,547 | 36,808 | 483 | 15,641 | 25,463 |
| Fort Necessity NB | 264,450 | 1,105 | 8,453 | 7,427 | 113 | 2,594 | 4,174 |
| Fort Point NHS | 1,315,241 | 0 | 85,048 | 79,158 | 879 | 40,929 | 67,094 |
| Fort Pulaski NM | 416,292 | 29 | 20,707 | 19,273 | 295 | 8,601 | 14,244 |
| Fort Raleigh NHS | 305,711 | 0 | 10,644 | 9,907 | 161 | 4,192 | 7,002 |
| Fort Scott NHS | 27,635 | 0 | 962 | 896 | 15 | 298 | 481 |
| Fort Smith NHS | 68,678 | 0 | 3,416 | 3,180 | 57 | 1,261 | 2,047 |
| *Fort Stanwix NM | 103,748 | 0 | 3,795 | 3,632 | 54 | 1,425 | 2,260 |
| Fort Sumter NM | 797,713 | 2 | 18,408 | 16,389 | 238 | 6,422 | 10,521 |
| Fort Union NM | 10,638 | 0 | 631 | 631 | 9 | 210 | 351 |
| Fort Union Trading Post NHS | 14,458 | 0 | 985 | 955 | 15 | 322 | 528 |
| Fort Vancouver NHS | 786,989 | 0 | 39,146 | 36,435 | 625 | 19,724 | 32,614 |
| Fort Washington Park | 352,883 | 0 | 11,443 | 10,476 | 125 | 5,291 | 8,672 |
| Fossil Butte NM | 19,700 | 0 | 840 | 840 | 12 | 280 | 470 |

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010 (continued)

| | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| **Park Unit** | **2010 Recreation Visits** | **2010 Overnight Stays** | **All Visitors ($000's)** | **Non-Local Visitors ($000's)** | **Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Franklin Delano Roosevelt Memorial | 2,238,052 | 0 | 72,571 | 66,441 | 792 | 33,554 | 55,002 |
| Frederick Douglass NHS | 44,699 | 0 | 1,449 | 1,327 | 16 | 670 | 1,099 |
| Frederick Law Olmsted NHS | 3,285 | 0 | 212 | 198 | 3 | 107 | 173 |
| Fredericksburg & Spotsylvania NMP | 899,936 | 0 | 44,764 | 41,664 | 595 | 15,755 | 26,228 |
| Friendship Hill NHS | 32,562 | 0 | 2,106 | 1,960 | 31 | 723 | 1,183 |
| Gates of the Arctic NP & PRES | 10,840 | 7,175 | 3,422 | 3,422 | 39 | 1,329 | 2,303 |
| Gateway NRA | 8,820,757 | 12,985 | 161,040 | 65,265 | 750 | 35,747 | 58,536 |
| Gauley River NRA | 107,223 | 4,082 | 4,440 | 3,875 | 58 | 1,511 | 2,451 |
| General Grant NMEM | 119,665 | 0 | 7,738 | 7,202 | 83 | 4,028 | 6,566 |
| George Rogers Clark NHP | 118,912 | 0 | 5,915 | 5,505 | 92 | 1,822 | 2,959 |
| *George Washington Birthplace NM | 128,158 | 0 | 2,964 | 1,868 | 28 | 591 | 971 |
| George Washington Carver NM | 35,068 | 0 | 546 | 546 | 8 | 190 | 305 |
| George Washington MEM PKWY | 6,925,099 | 0 | 29,729 | 4,337 | 51 | 1,990 | 3,215 |
| *Gettysburg NMP | 1,031,554 | 25,944 | 63,573 | 63,066 | 1,051 | 24,153 | 39,159 |
| Gila Cliff Dwellings NM | 32,652 | 0 | 861 | 830 | 13 | 238 | 388 |
| Glacier Bay NP & PRES | 444,530 | 15,221 | 3,161 | 3,161 | 40 | 1,329 | 2,259 |
| Glacier NP | 2,200,048 | 372,371 | 108,880 | 104,690 | 1,632 | 41,958 | 70,696 |
| Glen Canyon NRA | 2,124,467 | 1,600,687 | 181,609 | 181,609 | 2,278 | 68,395 | 100,298 |
| Golden Gate NRA | 14,271,503 | 57,499 | 264,151 | 109,666 | 1,451 | 59,795 | 99,870 |
| *Golden Spike NHS | 43,561 | 0 | 2,068 | 2,019 | 32 | 756 | 1,224 |
| Governors Island NM | 409,207 | 0 | 36,111 | 34,278 | 397 | 19,442 | 31,718 |
| *Grand Canyon NP | 4,388,386 | 1,245,883 | 415,797 | 415,797 | 6,167 | 167,945 | 265,834 |
| Grand Portage NM | 113,996 | 210 | 12,569 | 12,506 | 197 | 4,510 | 7,495 |
| *Grand Teton NP | 2,669,374 | 517,670 | 424,041 | 420,201 | 6,258 | 162,404 | 269,247 |
| Grant-Kohrs Ranch NHS | 22,075 | 0 | 769 | 715 | 12 | 305 | 509 |
| Great Basin NP | 88,870 | 35,933 | 4,128 | 3,959 | 55 | 1,149 | 1,856 |
| Great Sand Dunes NP & PRES | 283,284 | 49,826 | 10,231 | 9,602 | 141 | 3,291 | 5,365 |
| Great Smoky Mountains NP | 9,463,538 | 393,812 | 818,195 | 792,547 | 11,367 | 303,510 | 504,948 |
| Greenbelt Park | 270,661 | 55,747 | 18,366 | 17,266 | 203 | 8,483 | 13,511 |
| Guadalupe Mountains NP | 192,210 | 17,445 | 12,973 | 12,341 | 193 | 3,730 | 6,158 |
| Guilford Courthouse NMP | 285,444 | 7 | 14,198 | 13,215 | 228 | 6,276 | 10,182 |
| Gulf Islands NS | 4,283,747 | 69,973 | 118,718 | 68,675 | 1,006 | 26,759 | 44,172 |
| Hagerman Fossil Beds NM | 29,795 | 0 | 901 | 787 | 13 | 294 | 480 |
| Haleakala NP | 1,105,606 | 21,126 | 74,966 | 71,195 | 861 | 32,974 | 54,523 |
| Hamilton Grange NMEM | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hampton NHS | 32,153 | 0 | 2,079 | 1,935 | 25 | 822 | 1,339 |
| Harpers Ferry NHP | 268,822 | 0 | 10,000 | 9,134 | 129 | 4,051 | 6,556 |
| Harry S Truman NHS | 27,670 | 0 | 1,789 | 1,665 | 28 | 926 | 1,577 |
| Hawaii Volcanoes NP | 1,304,667 | 77,320 | 88,258 | 83,901 | 1,162 | 40,232 | 66,892 |
| Herbert Hoover NHS | 142,512 | 0 | 7,089 | 6,598 | 111 | 2,735 | 4,524 |

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010 (continued)

| Park Unit | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| | 2010 Recreation Visits | 2010 Overnight Stays | All Visitors ($000's) | Non-Local Visitors ($000's) | Jobs | Labor Income ($000's) | Value Added ($000's) |
| Home of Franklin D. Roosevelt NHS | 140,251 | 0 | 2,852 | 2,509 | 36 | 1,058 | 1,719 |
| *Homestead National Monument of America | 74,314 | 0 | 2,265 | 2,121 | 36 | 789 | 1,272 |
| Hopewell Culture NHP | 33,918 | 0 | 1,181 | 1,099 | 17 | 381 | 615 |
| Hopewell Furnace NHS | 55,750 | 0 | 2,773 | 2,581 | 41 | 1,210 | 1,972 |
| Horseshoe Bend NMP | 67,776 | 0 | 3,371 | 3,138 | 51 | 1,100 | 1,796 |
| Hot Springs NP | 1,311,807 | 12,409 | 89,001 | 84,505 | 1,411 | 30,685 | 50,436 |
| Hovenweep NM | 27,386 | 1,696 | 1,382 | 1,291 | 18 | 485 | 807 |
| Hubbell Trading Post NHS | 80,578 | 0 | 4,008 | 3,730 | 53 | 1,121 | 1,901 |
| Independence NHP | 3,751,007 | 0 | 146,515 | 131,163 | 1,915 | 69,968 | 115,401 |
| Indiana Dunes NL | 2,150,345 | 24,401 | 63,495 | 44,456 | 658 | 16,276 | 26,706 |
| Isle Royale NP | 15,793 | 48,953 | 1,959 | 1,959 | 29 | 640 | 1,056 |
| *James A. Garfield NHS | 24,853 | 0 | 766 | 700 | 11 | 341 | 566 |
| Jean Lafitte NHP & PRES | 391,019 | 0 | 19,450 | 18,103 | 260 | 9,081 | 15,107 |
| Jefferson National Expansion Memorial | 2,436,110 | 0 | 98,436 | 86,619 | 1,309 | 37,404 | 60,984 |
| Jewel Cave NM | 103,462 | 0 | 5,146 | 4,790 | 82 | 1,955 | 3,224 |
| Jimmy Carter NHS | 64,849 | 0 | 2,258 | 2,102 | 36 | 687 | 1,114 |
| John D Rockefeller Jr. MEM PKWY | 1,222,931 | 33,531 | 7,063 | 6,527 | 90 | 2,336 | 3,818 |
| *John Day Fossil Beds NM | 135,151 | 5 | 6,119 | 6,025 | 75 | 1,674 | 2,752 |
| John F. Kennedy NHS | 17,466 | 0 | 1,129 | 1,051 | 14 | 570 | 920 |
| John Muir NHS | 34,904 | 0 | 2,257 | 2,101 | 30 | 1,004 | 1,663 |
| Johnstown Flood NMEM | 100,799 | 0 | 5,704 | 5,274 | 93 | 2,293 | 3,728 |
| *Joshua Tree NP | 1,434,976 | 287,765 | 37,485 | 32,677 | 378 | 11,892 | 18,926 |
| Kalaupapa NHP | 27,919 | 0 | 1,389 | 1,293 | 16 | 591 | 973 |
| Kaloko-Honokohau NHP | 132,731 | 0 | 6,602 | 6,145 | 85 | 2,921 | 4,841 |
| *Katmai NP & PRES/Aniakchak NM & PRES | 55,172 | 6,697 | 13,102 | 12,952 | 133 | 3,686 | 5,778 |
| Kenai Fjords NP | 297,596 | 2,976 | 9,468 | 9,331 | 129 | 4,156 | 7,080 |
| Kennesaw Mountain NBP | 1,512,191 | 0 | 47,531 | 41,342 | 582 | 20,220 | 33,291 |
| *Kings Mountain NMP | 275,555 | 86 | 9,469 | 8,449 | 136 | 3,114 | 5,149 |
| Klondike Gold Rush NHP Alaska | 797,716 | 7,237 | 20,821 | 20,572 | 267 | 8,769 | 14,882 |
| Klondike Gold Rush NHP Seattle | 65,870 | 0 | 4,259 | 3,964 | 59 | 2,143 | 3,568 |
| Knife River Indian Villages NHS | 21,721 | 0 | 756 | 704 | 13 | 297 | 485 |
| Kobuk Valley NP | 3,164 | 503 | 996 | 996 | 11 | 382 | 653 |
| Korean War Veterans Memorial | 3,072,716 | 0 | 99,636 | 91,219 | 1,087 | 46,068 | 75,515 |
| Lake Chelan NRA | 39,249 | 10,200 | 1,555 | 1,426 | 20 | 760 | 1,272 |
| Lake Clark NP & PRES | 9,931 | 5,149 | 3,133 | 3,133 | 35 | 1,212 | 2,093 |
| Lake Mead NRA | 7,080,758 | 770,988 | 254,878 | 216,693 | 2,452 | 84,942 | 132,977 |
| Lake Meredith NRA | 883,586 | 22,249 | 36,452 | 31,762 | 435 | 10,337 | 16,026 |
| Lake Roosevelt NRA | 1,324,074 | 159,938 | 39,811 | 35,121 | 515 | 12,807 | 20,755 |

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010 (continued)

| | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| **Park Unit** | **2010 Recreation Visits** | **2010 Overnight Stays** | **All Visitors ($000's)** | **Non-Local Visitors ($000's)** | **Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Lassen Volcanic NP | 384,570 | 98,686 | 16,053 | 14,634 | 207 | 5,933 | 9,403 |
| Lava Beds NM | 130,765 | 9,915 | 4,494 | 4,288 | 56 | 1,408 | 2,263 |
| LBJ Memorial Grove on the Potomac | 230,694 | 0 | 14,917 | 13,884 | 165 | 6,863 | 11,075 |
| Lewis & Clark NHP | 218,553 | 0 | 10,871 | 10,118 | 154 | 3,380 | 5,515 |
| Lincoln Boyhood NMEM | 126,228 | 0 | 6,279 | 5,844 | 97 | 2,049 | 3,356 |
| Lincoln Home NHS | 354,125 | 0 | 18,516 | 18,178 | 285 | 7,796 | 12,568 |
| Lincoln Memorial | 6,042,315 | 0 | 195,929 | 179,377 | 2,138 | 90,590 | 148,495 |
| Little Bighorn Battlefield NM | 320,959 | 0 | 11,175 | 10,402 | 174 | 4,438 | 7,401 |
| Little River Canyon NPRES | 192,576 | 0 | 9,151 | 8,686 | 149 | 3,141 | 5,138 |
| Little Rock Central High School NHS | 49,740 | 0 | 2,474 | 2,303 | 38 | 1,118 | 1,817 |
| Longfellow NHS | 45,684 | 0 | 2,272 | 2,115 | 28 | 1,037 | 1,684 |
| Lowell NHP | 540,475 | 0 | 34,949 | 32,529 | 435 | 15,947 | 25,897 |
| Lyndon B. Johnson NHP | 112,680 | 0 | 7,286 | 6,782 | 93 | 2,911 | 4,811 |
| Maggie L Walker NHS | 12,331 | 0 | 291 | 154 | 2 | 74 | 123 |
| Mammoth Cave NP | 497,225 | 84,484 | 32,841 | 31,052 | 530 | 12,290 | 19,826 |
| Manassas NBP | 612,490 | 0 | 8,267 | 7,911 | 97 | 3,333 | 5,462 |
| *Manzanar NHS | 76,592 | 0 | 7,565 | 7,518 | 87 | 2,351 | 3,887 |
| Marsh-Billings-Rockefeller NHP | 31,209 | 0 | 1,552 | 1,445 | 21 | 617 | 1,016 |
| Martin Luther King, Jr. NHS | 658,452 | 0 | 42,578 | 39,629 | 532 | 19,950 | 32,839 |
| Martin Van Buren NHS | 21,055 | 0 | 418 | 365 | 5 | 139 | 219 |
| Mary McLeod Bethune Council House NHS | 19,520 | 0 | 633 | 579 | 7 | 293 | 480 |
| Mesa Verde NP | 559,712 | 95,496 | 41,346 | 39,597 | 560 | 14,816 | 24,238 |
| Minute Man NHP | 1,073,748 | 0 | 69,432 | 64,624 | 865 | 31,682 | 51,449 |
| *Minuteman Missile NHS | 42,348 | 0 | 2,811 | 2,811 | 46 | 1,137 | 1,881 |
| Missouri National Recreational River | 167,301 | 0 | 7,950 | 7,546 | 156 | 2,325 | 3,800 |
| Mojave NPRES | 600,897 | 1,744 | 12,891 | 11,255 | 142 | 5,078 | 8,236 |
| *Monocacy NB | 33,313 | 0 | 2,399 | 2,227 | 27 | 1,071 | 1,782 |
| Montezuma Castle NM | 578,554 | 0 | 28,778 | 26,785 | 415 | 13,872 | 23,113 |
| Moores Creek NB | 51,326 | 271 | 1,783 | 1,660 | 29 | 678 | 1,140 |
| Morristown NHP | 278,392 | 0 | 13,848 | 12,889 | 168 | 6,401 | 10,482 |
| *Mount Rainier NP | 1,191,754 | 172,838 | 35,389 | 33,696 | 484 | 14,150 | 22,832 |
| Mount Rushmore NMEM | 2,331,237 | 0 | 77,157 | 72,619 | 1,174 | 27,975 | 45,607 |
| Muir Woods NM | 834,356 | 0 | 53,952 | 50,216 | 643 | 27,440 | 45,733 |
| Natchez NHP | 206,870 | 0 | 10,290 | 9,577 | 136 | 3,015 | 5,027 |
| Natchez Trace PKWY | 5,910,950 | 21,201 | 88,326 | 32,079 | 454 | 9,959 | 15,958 |
| National Capital Parks-Central | 1,363,389 | 0 | 44,210 | 40,475 | 482 | 20,441 | 33,507 |
| National Capital Parks-East | 1,181,960 | 0 | 38,326 | 35,089 | 418 | 17,721 | 29,048 |
| Natural Bridges NM | 95,676 | 5,781 | 4,828 | 4,507 | 64 | 1,410 | 2,346 |
| Navajo NM | 90,696 | 2,933 | 4,538 | 4,230 | 56 | 1,504 | 2,443 |
| New Bedford Whaling NHP | 277,681 | 0 | 12,215 | 12,215 | 202 | 6,461 | 10,587 |

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010 (continued)

| Park Unit | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| | 2010 Recreation Visits | 2010 Overnight Stays | All Visitors ($000's) | Non-Local Visitors ($000's) | Jobs | Labor Income ($000's) | Value Added ($000's) |
| New Orleans Jazz NHP | 80,195 | 0 | 3,989 | 3,713 | 53 | 1,862 | 3,098 |
| *New River Gorge NR | 1,151,213 | 10,008 | 46,023 | 43,266 | 553 | 10,761 | 16,934 |
| Nez Perce NHP | 193,000 | 0 | 6,720 | 6,255 | 106 | 2,362 | 3,840 |
| Nicodemus NHS | 3,448 | 0 | 156 | 152 | 2 | 37 | 57 |
| Ninety Six NHS | 63,747 | 0 | 3,171 | 2,951 | 48 | 1,013 | 1,654 |
| Niobrara NSR | 69,705 | 0 | 3,312 | 3,144 | 65 | 969 | 1,583 |
| Noatak NPRES | 3,257 | 540 | 1,026 | 1,026 | 12 | 393 | 672 |
| North Cascades NP | 24,659 | 17,801 | 1,535 | 1,474 | 21 | 770 | 1,289 |
| Obed Wild and Scenic River | 180,203 | 1,269 | 7,692 | 6,727 | 105 | 2,466 | 3,945 |
| Ocmulgee NM | 109,413 | 0 | 5,442 | 5,065 | 88 | 2,166 | 3,558 |
| *Olympic NP | 2,844,563 | 300,891 | 103,099 | 94,596 | 1,395 | 34,906 | 57,102 |
| Oregon Caves NM | 86,335 | 6,560 | 4,113 | 3,829 | 62 | 1,559 | 2,529 |
| Organ Pipe Cactus NM | 209,602 | 23,690 | 10,692 | 10,007 | 156 | 5,182 | 8,624 |
| Ozark National Scenic Riverways | 1,416,529 | 173,952 | 63,351 | 56,183 | 888 | 19,332 | 30,592 |
| Padre Island NS | 612,716 | 67,261 | 41,287 | 39,292 | 640 | 16,806 | 27,603 |
| Palo Alto Battlefield NHP | 26,865 | 0 | 935 | 871 | 15 | 356 | 581 |
| Pea Ridge NMP | 115,128 | 0 | 5,727 | 5,330 | 96 | 1,747 | 2,875 |
| Pecos NHP | 33,864 | 0 | 736 | 712 | 11 | 319 | 524 |
| Pennsylvania Avenue NHS | 262,030 | 0 | 8,497 | 7,779 | 93 | 3,929 | 6,440 |
| *Perry's Victory and International Peace MEM | 92,944 | 1,685 | 7,150 | 7,150 | 145 | 3,494 | 5,686 |
| Petersburg NB | 175,553 | 0 | 8,732 | 8,127 | 137 | 3,447 | 5,783 |
| Petrified Forest NP | 664,725 | 300 | 45,120 | 42,830 | 641 | 14,963 | 24,659 |
| Petroglyph NM | 105,643 | 0 | 4,399 | 3,576 | 62 | 1,715 | 2,846 |
| *Pictured Rocks NL | 499,281 | 28,855 | 20,955 | 20,596 | 339 | 5,297 | 8,615 |
| Pinnacles NM | 246,575 | 10,360 | 4,836 | 4,034 | 48 | 1,782 | 2,928 |
| Pipe Spring NM | 59,952 | 0 | 2,982 | 2,776 | 39 | 1,049 | 1,706 |
| Pipestone NM | 78,108 | 0 | 3,362 | 3,264 | 56 | 1,438 | 2,363 |
| Piscataway Park | 248,314 | 0 | 8,052 | 7,372 | 88 | 3,723 | 6,103 |
| Point Reyes NS | 2,067,271 | 39,421 | 84,725 | 77,224 | 981 | 41,182 | 67,880 |
| President's Park | 616,635 | 0 | 19,995 | 18,306 | 218 | 9,245 | 15,154 |
| Prince William Forest Park | 386,521 | 49,050 | 20,715 | 15,517 | 185 | 7,775 | 12,005 |
| Pu'uhonua o Honaunau NHP | 419,590 | 0 | 20,871 | 19,426 | 269 | 9,233 | 15,303 |
| Puukohola Heiau NHS | 129,886 | 0 | 6,461 | 6,013 | 83 | 2,858 | 4,737 |
| Rainbow Bridge NM | 104,501 | 0 | 5,198 | 4,838 | 62 | 1,687 | 2,719 |
| Redwood NP | 418,820 | 7,479 | 20,717 | 18,693 | 268 | 6,565 | 10,453 |
| Richmond NBP | 130,415 | 0 | 9,194 | 8,293 | 134 | 4,042 | 6,700 |
| Rio Grande Wild and Scenic River | 1,103 | 6,046 | 121 | 119 | 2 | 36 | 60 |
| Rock Creek Park | 1,883,457 | 0 | 61,073 | 55,914 | 666 | 28,238 | 46,288 |
| Rocky Mountain NP | 2,955,821 | 174,202 | 170,804 | 170,804 | 2,641 | 77,625 | 129,666 |
| Roger Williams NMEM | 51,559 | 0 | 3,334 | 3,103 | 49 | 1,653 | 2,674 |
| Ross Lake NRA | 682,736 | 67,898 | 20,458 | 18,008 | 254 | 9,369 | 15,616 |

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010 (continued)

| | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| **Park Unit** | **2010 Recreation Visits** | **2010 Overnight Stays** | **All Visitors ($000's)** | **Non-Local Visitors ($000's)** | **Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Russell Cave NM | 23,374 | 0 | 1,163 | 1,082 | 18 | 363 | 589 |
| Sagamore Hill NHS | 55,149 | 0 | 3,566 | 3,319 | 42 | 1,726 | 2,820 |
| Saguaro NP | 717,614 | 1,568 | 24,161 | 16,752 | 229 | 6,426 | 10,477 |
| Saint Croix NSR | 188,400 | 25,884 | 5,660 | 4,990 | 80 | 2,166 | 3,534 |
| Saint Paul's Church NHS | 16,362 | 0 | 1,058 | 985 | 11 | 551 | 898 |
| *Saint-Gaudens NHS | 30,941 | 0 | 1,169 | 1,076 | 17 | 477 | 790 |
| Salem Maritime NHS | 806,506 | 0 | 52,151 | 48,540 | 642 | 21,185 | 34,276 |
| Salinas Pueblo Missions NM | 32,941 | 0 | 847 | 816 | 13 | 373 | 614 |
| San Antonio Missions NHP | 1,304,690 | 0 | 50,961 | 45,622 | 701 | 21,159 | 34,908 |
| San Francisco Maritime NHP | 4,130,970 | 10,946 | 86,294 | 63,899 | 675 | 30,842 | 50,167 |
| San Juan Island NHP | 263,370 | 0 | 17,030 | 15,851 | 209 | 5,949 | 9,819 |
| San Juan NHS | 1,105,252 | 0 | 54,976 | 51,169 | 781 | 18,624 | 30,436 |
| Santa Monica Mountains NRA | 568,371 | 144 | 22,915 | 15,196 | 202 | 7,572 | 12,436 |
| Saratoga NHP | 63,719 | 0 | 2,219 | 2,065 | 28 | 776 | 1,249 |
| Saugus Iron Works NHS | 10,775 | 0 | 697 | 648 | 8 | 349 | 563 |
| Scotts Bluff NM | 133,795 | 0 | 4,318 | 3,519 | 65 | 1,326 | 2,102 |
| *Sequoia NP/ Kings Canyon NP[a] | 1,320,156 | 438,677 | 97,012 | 89,408 | 1,283 | 37,299 | 60,504 |
| Shenandoah NP | 1,253,386 | 301,700 | 71,751 | 63,347 | 968 | 25,199 | 41,107 |
| Shiloh NMP | 317,046 | 0 | 11,039 | 10,275 | 169 | 3,774 | 6,295 |
| Sitka NHP | 189,176 | 0 | 3,784 | 3,739 | 49 | 1,594 | 2,704 |
| *Sleeping Bear Dunes NL | 1,280,932 | 116,382 | 120,482 | 117,346 | 2,070 | 54,605 | 92,417 |
| Springfield Armory NHS | 16,876 | 0 | 1,091 | 1,016 | 15 | 521 | 847 |
| Statue of Liberty NM | 3,833,288 | 0 | 166,402 | 149,929 | 1,724 | 81,161 | 132,772 |
| Steamtown NHS | 104,855 | 0 | 3,651 | 3,398 | 57 | 1,582 | 2,541 |
| Stones River NB | 187,559 | 0 | 9,329 | 8,683 | 133 | 4,616 | 7,583 |
| Sunset Crater Volcano NM | 158,819 | 0 | 7,900 | 7,353 | 97 | 2,691 | 4,338 |
| Tallgrass Prairie NPRES | 22,047 | 0 | 1,048 | 994 | 16 | 308 | 498 |
| Thaddeus Kosciuszko NMEM | 2,888 | 0 | 187 | 174 | 3 | 97 | 159 |
| Theodore Roosevelt Birthplace NHS | 15,029 | 0 | 972 | 905 | 10 | 506 | 825 |
| Theodore Roosevelt Inaugural NHS | 17,491 | 0 | 1,131 | 1,053 | 17 | 497 | 796 |
| Theodore Roosevelt Island Park | 116,035 | 0 | 7,503 | 6,984 | 83 | 3,452 | 5,571 |
| Theodore Roosevelt NP | 623,748 | 28,868 | 29,562 | 28,094 | 503 | 10,127 | 16,337 |
| Thomas Edison NHP | 63,009 | 0 | 4,074 | 3,792 | 49 | 1,951 | 3,193 |
| Thomas Jefferson Memorial | 2,305,856 | 0 | 74,770 | 68,453 | 816 | 34,571 | 56,668 |
| Thomas Stone NHS | 6,004 | 0 | 388 | 361 | 5 | 137 | 226 |
| Timpanogos Cave NM | 120,241 | 0 | 7,775 | 7,237 | 124 | 3,647 | 5,996 |
| Timucuan Ecological & Historic PRES | 993,948 | 0 | 50,804 | 39,677 | 616 | 19,560 | 32,181 |
| Tonto NM | 60,497 | 0 | 3,009 | 2,801 | 44 | 1,476 | 2,465 |
| Tumacacori NHP | 39,866 | 0 | 1,388 | 1,292 | 18 | 520 | 851 |
| Tuskegee Airmen NHS | 60,827 | 0 | 3,026 | 2,816 | 45 | 938 | 1,527 |

**Table A-1**. Spending and Economic Impacts of National Park Visitors on Local Economies, CY 2010 (continued)

| Park Unit | Public Use Data | | Visitor Spending 2010 | | Impacts of Non-Local Visitor Spending | | |
|---|---|---|---|---|---|---|---|
| | 2010 Recreation Visits | 2010 Overnight Stays | All Visitors ($000's) | Non-Local Visitors ($000's) | Jobs | Labor Income ($000's) | Value Added ($000's) |
| Tuskegee Institute NHS | 23,230 | 0 | 1,155 | 1,075 | 17 | 358 | 583 |
| Tuzigoot NM | 103,274 | 0 | 5,137 | 4,781 | 74 | 2,476 | 4,126 |
| Ulysses S. Grant NHS | 39,967 | 0 | 2,584 | 2,405 | 37 | 1,070 | 1,739 |
| Upper Delaware SRR | 306,468 | 0 | 9,139 | 7,987 | 111 | 2,927 | 4,738 |
| *Valley Forge NHP | 1,617,511 | 750 | 58,195 | 41,560 | 631 | 24,681 | 40,781 |
| Vanderbilt Mansion NHS | 390,525 | 0 | 5,674 | 3,313 | 45 | 1,332 | 2,151 |
| Vicksburg NMP | 581,459 | 0 | 28,922 | 26,920 | 420 | 11,264 | 18,301 |
| Vietnam Veterans Memorial | 4,555,371 | 0 | 147,713 | 135,234 | 1,612 | 68,297 | 111,952 |
| *Virgin Islands NP | 493,477 | 87,981 | 61,123 | 61,123 | 1,084 | 25,077 | 40,089 |
| Voyageurs NP | 253,891 | 90,701 | 11,934 | 11,426 | 193 | 4,355 | 7,047 |
| Walnut Canyon NM | 126,552 | 0 | 6,295 | 5,859 | 77 | 2,144 | 3,457 |
| War in the Pacific NHP | 219,349 | 0 | 7,637 | 7,109 | 85 | 3,514 | 5,670 |
| Washington Monument | 628,665 | 0 | 20,385 | 18,663 | 222 | 9,425 | 15,450 |
| Washita Battlefield NHS | 12,552 | 0 | 489 | 460 | 8 | 153 | 252 |
| Weir Farm NHS | 19,313 | 0 | 1,249 | 1,162 | 13 | 590 | 965 |
| Whiskeytown-Shasta-Trinity NRA | 788,065 | 44,789 | 32,774 | 28,653 | 420 | 11,504 | 18,340 |
| White House | 922,335 | 0 | 29,908 | 27,381 | 326 | 13,828 | 22,667 |
| White Sands NM | 470,921 | 1,811 | 16,427 | 16,109 | 250 | 5,157 | 8,552 |
| Whitman Mission NHS | 58,521 | 0 | 2,038 | 1,897 | 29 | 721 | 1,176 |
| William Howard Taft NHS | 21,163 | 0 | 1,368 | 1,274 | 20 | 629 | 1,023 |
| Wilson's Creek NB | 185,200 | 0 | 9,212 | 8,574 | 157 | 3,922 | 6,343 |
| Wind Cave NP | 577,141 | 3,263 | 51,500 | 51,500 | 925 | 22,350 | 37,231 |
| Wolf Trap NP for the Performing Arts | 520,397 | 0 | 33,651 | 31,320 | 373 | 15,482 | 24,983 |
| *Women's Rights NHP | 22,662 | 0 | 623 | 623 | 7 | 182 | 282 |
| World War II Memorial | 3,964,351 | 0 | 128,549 | 117,689 | 1,403 | 59,436 | 97,427 |
| World War II Valor in the Pacific NM | 1,372,724 | 0 | 53,619 | 48,001 | 719 | 25,114 | 41,525 |
| Wrangell-St Elias NP & PRES | 73,170 | 0 | 3,242 | 3,242 | 41 | 1,389 | 2,407 |
| Wright Brothers NMEM | 476,200 | 0 | 16,581 | 15,432 | 251 | 6,531 | 10,907 |
| Wupatki NM | 221,083 | 0 | 10,997 | 10,235 | 135 | 3,746 | 6,039 |
| *Yellowstone NP | 3,640,185 | 1,306,318 | 334,445 | 334,445 | 4,881 | 135,847 | 225,635 |
| *Yosemite NP | 3,901,408 | 1,720,909 | 354,689 | 350,244 | 4,602 | 132,465 | 215,932 |
| Yukon-Charley Rivers NPRES | 6,211 | 7,102 | 3,569 | 3,569 | 40 | 1,385 | 2,398 |
| *Zion NP | 2,665,972 | 304,208 | 123,727 | 122,606 | 2,136 | 53,476 | 85,771 |

[a] Sequoia and Kings Canyon national parks are combined for the economic analysis. Recreation visits for the two parks are reduced to reflect double counting between the two parks.

* For these parks, results are based on a visitor survey at the designated park. For other parks, visitor characteristics and spending averages are adapted from national averages for each park type, adjusted for surrounding populations and spending opportunities.

Notes: Non-local visitors live outside a roughly 60-mile radius of the park. Jobs include part-time and full-time jobs with seasonal jobs adjusted to an annual basis. Impacts include direct and secondary effects of visitor spending on the local economy. Labor income covers wages and salaries, payroll benefits, and incomes of sole proprietors in the local region. Value added includes labor income, profits and rents, and indirect business taxes.

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010

| | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| Park Unit | Salary ($000's) | Payroll Benefits ($000's) | NPS Jobs | Total Jobs | Labor Income ($000's) | Value Added ($000's) |
| Abraham Lincoln Birthplace NHS | 764 | 148 | 16 | 21 | 1,088 | 1,232 |
| Acadia NP | 6,743 | 1,687 | 142 | 184 | 9,800 | 10,878 |
| Adams NHS | 1,476 | 309 | 25 | 35 | 2,281 | 2,652 |
| Agate Fossil Beds NM | 464 | 119 | 11 | 14 | 658 | 718 |
| Allegheny Portage Railroad NHS | 1,464 | 429 | 29 | 38 | 2,179 | 2,424 |
| Amistad NRA | 1,985 | 621 | 40 | 48 | 2,806 | 3,018 |
| Andersonville NHS | 923 | 267 | 20 | 24 | 1,344 | 1,480 |
| Andrew Johnson NHS | 566 | 132 | 13 | 16 | 827 | 936 |
| Antietam NB | 2,990 | 811 | 56 | 73 | 4,580 | 5,220 |
| Apostle Islands NL | 2,430 | 684 | 36 | 48 | 3,438 | 3,728 |
| Appomattox Court House NHP | 1,171 | 314 | 27 | 32 | 1,666 | 1,847 |
| Arches NP | 1,067 | 308 | 24 | 28 | 1,475 | 1,586 |
| Arkansas Post NMEM | 545 | 136 | 14 | 16 | 751 | 823 |
| Arlington House, Robert E. Lee Mem | 801 | 221 | 21 | 23 | 1,165 | 1,284 |
| Assateague Island NS | 3,807 | 940 | 85 | 109 | 5,574 | 6,315 |
| Aztec Ruins NM | 1,204 | 318 | 25 | 31 | 1,726 | 1,917 |
| Badlands NP | 3,556 | 963 | 81 | 100 | 5,166 | 5,689 |
| Bandelier NM | 3,501 | 1,040 | 84 | 85 | 4,557 | 4,585 |
| Bent's Old Fort NHS | 813 | 195 | 20 | 22 | 1,083 | 1,154 |
| Bering Land Bridge NPRES | 135 | 32 | 3 | 3 | 195 | 221 |
| Big Bend NP | 5,756 | 1,709 | 123 | 141 | 7,959 | 8,576 |
| Big Cypress NPRES | 4,786 | 1,447 | 75 | 104 | 7,399 | 8,363 |
| Big South Fork NRRA | 3,138 | 921 | 56 | 68 | 4,408 | 4,787 |
| Big Thicket NPRES | 2,131 | 648 | 42 | 52 | 3,212 | 3,608 |
| Bighorn Canyon NRA | 2,457 | 666 | 47 | 62 | 3,618 | 4,051 |
| Biscayne NP | 3,004 | 888 | 58 | 79 | 4,741 | 5,455 |
| Black Canyon of the Gunnison NP | 1,216 | 292 | 29 | 33 | 1,620 | 1,748 |
| Blue Ridge Parkway | 11,892 | 3,336 | 265 | 302 | 16,267 | 17,385 |
| Bluestone NSR | 56 | 20 | 1 | 1 | 76 | 76 |
| Booker T. Washington NM | 602 | 189 | 12 | 15 | 903 | 1,005 |
| Boston African American NHS | 459 | 89 | 15 | 17 | 668 | 756 |
| Boston NHP | 5,803 | 1,677 | 88 | 115 | 8,992 | 10,111 |
| Brown V. Board of Education NHS | 687 | 221 | 13 | 18 | 1,084 | 1,232 |
| Bryce Canyon NP | 3,327 | 886 | 87 | 97 | 4,471 | 4,773 |
| Buck Island Reef NM | 216 | 52 | 5 | 5 | 287 | 307 |
| Buffalo National River | 4,617 | 1,412 | 110 | 130 | 6,596 | 7,196 |
| Cabrillo NM | 1,353 | 367 | 29 | 36 | 1,990 | 2,229 |
| Canaveral NS | 2,511 | 683 | 54 | 73 | 3,892 | 4,487 |
| Cane River Creole NHP | 760 | 194 | 15 | 18 | 1,062 | 1,159 |
| Canyon de Chelly NM | 1,816 | 488 | 41 | 46 | 2,456 | 2,633 |

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010 (continued)

| | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| Park Unit | Salary ($000's) | Payroll Benefits ($000's) | NPS Jobs | Total Jobs | Labor Income ($000's) | Value Added ($000's) |
| Canyonlands NP | 5,549 | 1,526 | 134 | 153 | 7,649 | 8,312 |
| Cape Cod NS | 6,532 | 1,640 | 108 | 144 | 9,652 | 10,981 |
| Cape Hatteras NS | 6,372 | 1,747 | 140 | 178 | 9,368 | 10,617 |
| Cape Lookout NS | 1,985 | 399 | 40 | 48 | 2,591 | 2,807 |
| Capitol Reef NP | 1,727 | 499 | 35 | 44 | 2,419 | 2,628 |
| Capulin Volcano NM | 423 | 111 | 12 | 13 | 559 | 586 |
| Carl Sandburg Home NHS | 930 | 203 | 24 | 28 | 1,279 | 1,407 |
| Carlsbad Caverns NP | 4,377 | 1,229 | 100 | 114 | 6,033 | 6,474 |
| Casa Grande Ruins NM | 685 | 187 | 15 | 15 | 875 | 877 |
| Castillo de San Marcos NM | 2,204 | 630 | 46 | 55 | 3,134 | 3,459 |
| Castle Clinton NM | 296 | 74 | 8 | 9 | 440 | 496 |
| Catoctin Mountain Park | 2,390 | 637 | 47 | 55 | 3,454 | 3,811 |
| Cedar Breaks NM | 608 | 125 | 16 | 20 | 845 | 946 |
| Chaco Culture NHP | 1,640 | 410 | 35 | 40 | 2,204 | 2,352 |
| Chamizal NMEM | 1,352 | 422 | 30 | 37 | 1,995 | 2,211 |
| Channel Islands NP | 4,536 | 1,218 | 87 | 107 | 6,705 | 7,474 |
| Charles Pinckney NHS | 370 | 107 | 6 | 9 | 555 | 628 |
| Chattahoochee River NRA | 2,247 | 621 | 42 | 52 | 3,298 | 3,663 |
| Chesapeake & Ohio Canal NHP | 7,200 | 1,948 | 147 | 172 | 10,431 | 11,507 |
| Chickamauga & Chattanooga NMP | 2,294 | 644 | 49 | 64 | 3,483 | 3,955 |
| Chickasaw NRA | 2,985 | 849 | 76 | 91 | 4,238 | 4,637 |
| Chiricahua NM | 913 | 243 | 21 | 23 | 1,227 | 1,308 |
| Christiansted NHS | 776 | 193 | 12 | 15 | 1,037 | 1,110 |
| City of Rocks NRES | 25 | 7 | 2 | 2 | 35 | 37 |
| Clara Barton NHS | 454 | 129 | 11 | 13 | 664 | 732 |
| Colonial NHP | 4,388 | 1,241 | 84 | 104 | 6,205 | 6,935 |
| Colorado NM | 1,838 | 452 | 38 | 46 | 2,548 | 2,788 |
| Congaree Swamp NM | 1,050 | 318 | 24 | 31 | 1,606 | 1,808 |
| Coronado NMEM | 1,084 | 357 | 19 | 24 | 1,615 | 1,773 |
| Cowpens NB | 457 | 121 | 13 | 16 | 682 | 770 |
| Crater Lake NP | 4,857 | 1,127 | 106 | 129 | 6,739 | 7,374 |
| Craters of the Moon NM | 1,178 | 324 | 21 | 24 | 1,582 | 1,673 |
| Cumberland Gap NHP | 2,703 | 840 | 57 | 68 | 3,863 | 4,190 |
| Cumberland Island NS | 1,616 | 505 | 27 | 37 | 2,489 | 2,801 |
| Curecanti NRA | 2,853 | 727 | 58 | 68 | 3,844 | 4,144 |
| Cuyahoga Valley NP | 8,284 | 2,125 | 178 | 220 | 12,112 | 13,499 |
| Dayton Aviation Heritage NHP | 1,183 | 297 | 23 | 30 | 1,740 | 1,952 |
| De Soto NMEM | 500 | 132 | 12 | 16 | 788 | 917 |
| Death Valley NP | 7,054 | 1,907 | 144 | 145 | 8,988 | 9,018 |
| Delaware Water Gap NRA | 7,344 | 1,882 | 121 | 164 | 10,919 | 12,404 |

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010 (continued)

| | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| Park Unit | Salary ($000's) | Payroll Benefits ($000's) | NPS Jobs | Total Jobs | Labor Income ($000's) | Value Added ($000's) |
| Denali NP & Pres | 12,495 | 2,552 | 209 | 212 | 15,156 | 15,227 |
| Devils Tower NM | 1,113 | 272 | 25 | 31 | 1,564 | 1,724 |
| Dinosaur NM | 2,468 | 640 | 53 | 60 | 3,347 | 3,623 |
| Dry Tortugas NP | 848 | 214 | 16 | 20 | 1,190 | 1,336 |
| Edgar Allan Poe NHS | 293 | 92 | 5 | 7 | 473 | 543 |
| Effigy Mounds NM | 1,053 | 226 | 31 | 36 | 1,423 | 1,559 |
| Eisenhower NHS | 852 | 249 | 16 | 19 | 1,201 | 1,305 |
| El Malpais NM | 1,301 | 397 | 28 | 38 | 2,024 | 2,303 |
| El Morro NM | 572 | 158 | 14 | 16 | 782 | 846 |
| Eleanor Roosevelt NHS | 265 | 53 | 7 | 8 | 366 | 409 |
| Eugene O'Neill NHS | 365 | 94 | 8 | 10 | 557 | 636 |
| Everglades NP | 17,425 | 5,032 | 304 | 408 | 26,701 | 30,211 |
| Federal Hall NMEM | 279 | 71 | 10 | 11 | 416 | 469 |
| Fire Island NS | 3,344 | 814 | 57 | 72 | 4,934 | 5,574 |
| Flight 93 NMEM | 573 | 130 | 11 | 15 | 808 | 896 |
| Florissant Fossil Beds NM | 752 | 202 | 19 | 22 | 1,072 | 1,186 |
| Fort Bowie NHS | 258 | 71 | 6 | 7 | 349 | 372 |
| Fort Caroline NMEM | 1,563 | 436 | 37 | 46 | 2,358 | 2,661 |
| Fort Davis NHS | 965 | 242 | 23 | 26 | 1,281 | 1,379 |
| Fort Donelson NB | 906 | 274 | 18 | 21 | 1,271 | 1,367 |
| Fort Frederica NM | 487 | 159 | 10 | 12 | 724 | 796 |
| Fort Laramie NHS | 1,172 | 316 | 27 | 32 | 1,643 | 1,800 |
| Fort Larned NHS | 707 | 214 | 17 | 21 | 1,028 | 1,120 |
| Fort Matanzas NM | 101 | 39 | 3 | 3 | 153 | 168 |
| Fort McHenry NM & HS | 1,669 | 410 | 40 | 46 | 2,333 | 2,561 |
| Fort Necessity NB | 1,008 | 306 | 18 | 24 | 1,472 | 1,620 |
| Fort Point NHS | 342 | 72 | 6 | 7 | 485 | 545 |
| Fort Pulaski NM | 1,020 | 219 | 28 | 34 | 1,446 | 1,629 |
| Fort Raleigh NHS | 265 | 72 | 10 | 12 | 389 | 441 |
| Fort Scott NHS | 871 | 194 | 18 | 21 | 1,162 | 1,267 |
| Fort Smith NHS | 678 | 189 | 15 | 19 | 976 | 1,071 |
| Fort Stanwix NM | 929 | 269 | 19 | 23 | 1,339 | 1,453 |
| Fort Sumter NM | 1,308 | 329 | 27 | 35 | 1,913 | 2,170 |
| Fort Union NM | 844 | 203 | 23 | 27 | 1,152 | 1,255 |
| Fort Union Trading Post NHS | 585 | 124 | 14 | 16 | 781 | 849 |
| Fort Vancouver NHS | 1,610 | 406 | 38 | 50 | 2,494 | 2,879 |
| Fossil Butte NM | 519 | 123 | 11 | 13 | 700 | 764 |
| Frederick Douglass NHS | 415 | 68 | 12 | 14 | 556 | 618 |
| Frederick Law Olmsted NHS | 1,232 | 335 | 19 | 24 | 1,887 | 2,125 |
| Fredericksburg & Spotsylvania NMP | 3,071 | 812 | 55 | 66 | 4,252 | 4,693 |

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010 (continued)

| Park Unit | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| | Salary ($000's) | Payroll Benefits ($000's) | NPS Jobs | Total Jobs | Labor Income ($000's) | Value Added ($000's) |
| Friendship Hill NHS | 450 | 161 | 7 | 10 | 682 | 748 |
| Gates of the Arctic NP & Pres | 1,585 | 366 | 37 | 45 | 2,283 | 2,585 |
| Gateway NRA | 18,772 | 4,277 | 361 | 433 | 27,521 | 31,071 |
| Gauley River NRA | 541 | 228 | 12 | 14 | 859 | 935 |
| General Grant NMEM | 220 | 67 | 6 | 6 | 339 | 381 |
| George Rogers Clark NHP | 616 | 178 | 12 | 15 | 856 | 922 |
| George Washington Birthplace N | 1,024 | 279 | 29 | 32 | 1,388 | 1,509 |
| George Washington Carver NM | 734 | 177 | 17 | 21 | 1,019 | 1,114 |
| George Washington Memorial Pkwy | 6,506 | 1,712 | 134 | 156 | 9,377 | 10,349 |
| Gettysburg NMP | 4,963 | 1,145 | 71 | 90 | 6,693 | 7,296 |
| Gila Cliff Dwellings NM | 236 | 53 | 5 | 5 | 304 | 324 |
| Glacier Bay NP & Pres | 4,902 | 1,181 | 72 | 98 | 7,113 | 8,047 |
| Glacier NP | 12,176 | 2,875 | 286 | 362 | 17,349 | 19,510 |
| Glen Canyon NRA | 8,441 | 2,280 | 182 | 209 | 11,615 | 12,528 |
| Golden Gate NRA | 14,669 | 3,779 | 265 | 337 | 22,267 | 25,391 |
| Golden Spike NHS | 656 | 190 | 15 | 18 | 947 | 1,037 |
| Governors Island NM | 738 | 153 | 14 | 17 | 1,066 | 1,205 |
| Grand Canyon NP | 26,870 | 7,448 | 571 | 658 | 37,236 | 40,174 |
| Grand Portage NM | 735 | 189 | 17 | 20 | 1,003 | 1,089 |
| Grand Teton NP | 12,741 | 3,318 | 284 | 335 | 17,644 | 19,375 |
| Grant-Kohrs Ranch NHS | 926 | 251 | 22 | 28 | 1,364 | 1,529 |
| Great Basin NP | 2,425 | 648 | 52 | 56 | 3,165 | 3,346 |
| Great Sand Dunes NM | 1,929 | 474 | 35 | 43 | 2,630 | 2,840 |
| Great Smoky Mountains NP | 14,993 | 4,426 | 339 | 399 | 21,284 | 23,320 |
| Greenbelt Park | 759 | 174 | 14 | 17 | 1,068 | 1,181 |
| Guadalupe Mountains NP | 2,112 | 588 | 60 | 65 | 2,853 | 3,033 |
| Guilford Courthouse NMP | 761 | 225 | 17 | 22 | 1,180 | 1,337 |
| Gulf Islands NS | 5,389 | 1,435 | 127 | 158 | 7,823 | 8,781 |
| Hagerman Fossil Beds NM | 498 | 116 | 11 | 14 | 682 | 749 |
| Haleakala NP | 4,695 | 1,225 | 95 | 121 | 6,860 | 7,744 |
| Hamilton Grange NMEM | 157 | 45 | 3 | 4 | 239 | 269 |
| Hampton NHS | 984 | 252 | 28 | 32 | 1,386 | 1,520 |
| Harpers Ferry NHP | 5,372 | 1,502 | 116 | 137 | 7,662 | 8,414 |
| Harry S Truman NHS | 898 | 270 | 19 | 31 | 1,690 | 2,088 |
| Hawaii Volcanoes NP | 7,290 | 1,873 | 148 | 194 | 10,707 | 12,144 |
| Herbert Hoover NHS | 1,005 | 264 | 24 | 30 | 1,469 | 1,649 |
| Home of Franklin D. Roosevelt | 901 | 265 | 18 | 22 | 1,329 | 1,477 |
| Homestead National Monument of America | 877 | 256 | 24 | 30 | 1,302 | 1,447 |
| Hopewell Culture NHP | 706 | 156 | 17 | 20 | 958 | 1,053 |
| Hopewell Furnace NHS | 1,149 | 267 | 19 | 26 | 1,675 | 1,897 |

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010 (continued)

| Park Unit | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| | **Salary ($000's)** | **Payroll Benefits ($000's)** | **NPS Jobs** | **Total Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Horseshoe Bend NMP | 509 | 150 | 12 | 14 | 727 | 798 |
| Hot Springs NP | 3,245 | 824 | 73 | 90 | 4,539 | 4,991 |
| Hovenweep NM | 387 | 121 | 7 | 9 | 556 | 607 |
| Hubbell Trading Post NHS | 714 | 169 | 14 | 15 | 915 | 974 |
| Independence NHP | 12,293 | 3,320 | 179 | 255 | 19,337 | 22,269 |
| Indiana Dunes NL | 6,828 | 1,891 | 129 | 169 | 10,033 | 11,226 |
| Isle Royale NP | 3,190 | 763 | 64 | 78 | 4,338 | 4,726 |
| Jean Lafitte NHP & PRES | 3,069 | 904 | 58 | 75 | 4,633 | 5,198 |
| Jefferson National Expansion Memorial | 8,090 | 2,472 | 180 | 221 | 12,112 | 13,434 |
| Jewel Cave NM | 1,019 | 233 | 30 | 36 | 1,451 | 1,623 |
| Jimmy Carter NHS | 898 | 293 | 20 | 24 | 1,294 | 1,404 |
| John D Rockefeller Jr. Mem Pkwy | 413 | 117 | 7 | 9 | 581 | 634 |
| John Day Fossil Beds NM | 1,099 | 305 | 24 | 25 | 1,451 | 1,507 |
| John Fitzgerald Kennedy NHS | 373 | 90 | 7 | 9 | 561 | 633 |
| John Muir NHS | 765 | 189 | 15 | 19 | 1,124 | 1,271 |
| Johnstown Flood NMEM | 573 | 176 | 13 | 16 | 863 | 961 |
| Joshua Tree NP | 6,338 | 1,699 | 140 | 162 | 8,837 | 9,604 |
| Kalaupapa NHP | 2,430 | 658 | 40 | 53 | 3,575 | 4,032 |
| Kaloko-Honokohau NHP | 1,113 | 336 | 24 | 31 | 1,686 | 1,905 |
| Katmai NP & Pres/Aniakchak | 2,974 | 649 | 44 | 44 | 3,623 | 3,623 |
| Kenai Fjords NP | 2,214 | 493 | 40 | 51 | 3,172 | 3,594 |
| Kennesaw Mountain NBP | 1,051 | 302 | 21 | 27 | 1,630 | 1,865 |
| Kings Mountain NMP | 811 | 210 | 19 | 23 | 1,136 | 1,248 |
| Klondike Gold Rush NHP Alaska | 2,660 | 622 | 39 | 54 | 3,840 | 4,347 |
| Klondike Gold Rush NHP Seattle | 492 | 136 | 15 | 18 | 768 | 885 |
| Knife River Indian Villages NHS | 582 | 160 | 14 | 17 | 862 | 958 |
| Lake Clark NP & Pres | 1,922 | 500 | 32 | 42 | 2,826 | 3,192 |
| Lake Mead NRA | 16,833 | 4,605 | 354 | 402 | 23,296 | 25,057 |
| Lake Meredith NRA | 2,336 | 712 | 51 | 54 | 3,178 | 3,255 |
| Lake Roosevelt NRA | 3,521 | 961 | 74 | 91 | 5,005 | 5,493 |
| Lassen Volcanic NP | 4,384 | 1,074 | 84 | 109 | 6,340 | 7,079 |
| Lava Beds NM | 2,061 | 583 | 45 | 52 | 2,883 | 3,105 |
| LBJ Memorial Grove on the Potomac | 33 | 9 | 3 | 3 | 48 | 53 |
| Lewis & Clark National Historic | 1,105 | 290 | 29 | 32 | 1,491 | 1,595 |
| Lincoln Boyhood NMEM | 690 | 208 | 16 | 19 | 991 | 1,087 |
| Lincoln Home NHS | 1,911 | 492 | 43 | 52 | 2,714 | 2,970 |
| Little Bighorn Battlefield NM | 980 | 243 | 23 | 29 | 1,420 | 1,593 |
| Little River Canyon NPRES | 966 | 285 | 23 | 28 | 1,401 | 1,545 |
| Little Rock Central High School | 694 | 188 | 15 | 19 | 1,015 | 1,120 |
| Longfellow NHS | 771 | 178 | 12 | 15 | 1,108 | 1,243 |

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010 (continued)

| Park Unit | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| | Salary ($000's) | Payroll Benefits ($000's) | NPS Jobs | Total Jobs | Labor Income ($000's) | Value Added ($000's) |
| Lowell NHP | 5,349 | 1,348 | 98 | 122 | 7,803 | 8,736 |
| Lyndon B. Johnson NHP | 2,348 | 668 | 54 | 64 | 3,407 | 3,757 |
| Maggie L Walker NHS | 422 | 103 | 10 | 12 | 619 | 699 |
| Mammoth Cave NP | 6,055 | 1,431 | 172 | 200 | 8,304 | 9,027 |
| Manassas NBP | 1,935 | 533 | 29 | 36 | 2,757 | 3,046 |
| Manzanar NHS | 883 | 216 | 16 | 18 | 1,154 | 1,228 |
| Marsh-Billings Rockefeller NHP | 1,286 | 301 | 26 | 33 | 1,862 | 2,092 |
| Martin Luther King Jr NHS | 2,084 | 491 | 42 | 51 | 2,975 | 3,313 |
| Martin Van Buren NHS | 818 | 191 | 18 | 21 | 1,140 | 1,243 |
| Mary McLeod Bethune Council House NHS | 475 | 96 | 12 | 13 | 656 | 727 |
| Mesa Verde NP | 5,739 | 1,381 | 131 | 154 | 7,917 | 8,682 |
| Minute Man NHP | 2,042 | 495 | 34 | 43 | 2,959 | 3,315 |
| Missouri National Recreational | 492 | 133 | 13 | 15 | 673 | 726 |
| Mojave NPRES | 3,740 | 1,093 | 69 | 86 | 5,609 | 6,232 |
| Monocacy NB | 1,250 | 356 | 24 | 29 | 1,819 | 2,018 |
| Montezuma Castle NM | 1,534 | 435 | 35 | 46 | 2,404 | 2,769 |
| Moores Creek NB | 308 | 92 | 8 | 10 | 455 | 512 |
| Morristown NHP | 1,824 | 499 | 29 | 37 | 2,707 | 3,041 |
| Mount Rainier NP | 10,547 | 2,473 | 232 | 283 | 14,957 | 16,620 |
| Mount Rushmore NMEM | 3,418 | 1,008 | 69 | 90 | 5,102 | 5,682 |
| Muir Woods NM | 784 | 195 | 14 | 17 | 1,171 | 1,330 |
| Natchez NHP | 998 | 324 | 21 | 23 | 1,375 | 1,462 |
| Natchez Trace Parkway | 7,176 | 2,424 | 156 | 178 | 10,228 | 10,902 |
| National Capital Parks Central | 14,278 | 3,593 | 288 | 338 | 20,416 | 22,549 |
| National Capital Parks East | 8,304 | 2,129 | 148 | 177 | 11,914 | 13,155 |
| Natural Bridges NM | 417 | 95 | 9 | 10 | 534 | 570 |
| Navajo NM | 745 | 175 | 18 | 21 | 1,000 | 1,083 |
| New Bedford Whaling NHP | 462 | 111 | 10 | 13 | 677 | 769 |
| New Orleans Jazz NHP | 551 | 157 | 15 | 18 | 827 | 928 |
| New River Gorge NR | 5,362 | 1,638 | 111 | 111 | 7,000 | 7,000 |
| Nez Perce NHP | 1,901 | 530 | 39 | 48 | 2,719 | 2,978 |
| Nicodemus NHS | 336 | 97 | 8 | 8 | 433 | 433 |
| Ninety Six NHS | 308 | 92 | 8 | 9 | 438 | 479 |
| Niobrara NSR | 540 | 153 | 12 | 14 | 747 | 804 |
| North Cascades NP | 7,152 | 1,905 | 152 | 192 | 10,909 | 12,504 |
| Obed Wild and Scenic River | 493 | 161 | 10 | 12 | 718 | 779 |
| Ocmulgee NM | 813 | 178 | 18 | 23 | 1,145 | 1,279 |
| Olympic NP | 10,885 | 2,835 | 229 | 278 | 15,238 | 16,777 |
| Oregon Caves NM | 1,154 | 268 | 28 | 35 | 1,633 | 1,811 |
| Organ Pipe Cactus NM | 2,488 | 758 | 40 | 58 | 3,971 | 4,575 |

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010 (continued)

| | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| Park Unit | Salary ($000's) | Payroll Benefits ($000's) | NPS Jobs | Total Jobs | Labor Income ($000's) | Value Added ($000's) |
| Ozark National Scenic Riverways | 5,242 | 1,517 | 91 | 127 | 7,831 | 8,752 |
| Padre Island NS | 3,470 | 903 | 75 | 96 | 5,083 | 5,660 |
| Palo Alto Battlefield NHS | 599 | 153 | 15 | 18 | 862 | 955 |
| Pea Ridge NMP | 881 | 240 | 23 | 27 | 1,233 | 1,350 |
| Pecos NHP | 1,340 | 425 | 29 | 39 | 2,092 | 2,367 |
| Perry's Victory and Internatl Peace Mem | 801 | 218 | 17 | 22 | 1,182 | 1,315 |
| Petersburg NB | 2,225 | 623 | 39 | 52 | 3,283 | 3,715 |
| Petrified Forest NP | 2,576 | 679 | 55 | 63 | 3,515 | 3,802 |
| Petroglyph NM | 1,231 | 312 | 25 | 35 | 1,865 | 2,138 |
| Pictured Rocks NL | 1,786 | 402 | 32 | 33 | 2,203 | 2,249 |
| Pinnacles NM | 2,444 | 646 | 48 | 56 | 3,486 | 3,858 |
| Pipe Spring NM | 808 | 201 | 18 | 22 | 1,133 | 1,247 |
| Pipestone NM | 506 | 141 | 12 | 16 | 765 | 866 |
| Piscataway Park | 294 | 77 | 7 | 8 | 424 | 468 |
| Point Reyes NS | 6,803 | 1,898 | 122 | 153 | 10,368 | 11,735 |
| Prince William Forest Park | 1,980 | 540 | 42 | 49 | 2,873 | 3,169 |
| Pu'uhonua o Honaunau NHP | 1,729 | 365 | 41 | 52 | 2,460 | 2,801 |
| Puukohola Heiau NHS | 1,005 | 235 | 25 | 31 | 1,453 | 1,651 |
| Rainbow Bridge NM | 95 | 27 | 3 | 3 | 132 | 142 |
| Redwood NP | 6,976 | 1,986 | 135 | 165 | 9,881 | 10,717 |
| Richmond NBP | 2,021 | 575 | 42 | 53 | 3,048 | 3,431 |
| Rio Grande Wild and Scenic River | 116 | 54 | 2 | 2 | 181 | 193 |
| Rock Creek Park | 3,775 | 923 | 79 | 92 | 5,371 | 5,936 |
| Rocky Mountain NP | 14,547 | 3,694 | 319 | 392 | 20,940 | 23,438 |
| Roger Williams NMEM | 370 | 103 | 9 | 12 | 589 | 678 |
| Russell Cave NM | 255 | 54 | 7 | 8 | 341 | 374 |
| Sagamore Hill NHS | 1,098 | 262 | 25 | 30 | 1,615 | 1,826 |
| Saguaro NP | 3,675 | 1,027 | 97 | 112 | 5,230 | 5,708 |
| Saint Croix NSR | 2,832 | 746 | 59 | 75 | 4,194 | 4,713 |
| Saint Paul's Church NHS | 5 | 2 | 1 | 1 | 8 | 9 |
| Saint-Gaudens NHS | 784 | 223 | 14 | 18 | 1,140 | 1,269 |
| Salem Maritime NHS | 1,902 | 474 | 44 | 51 | 2,694 | 2,981 |
| Salinas Pueblo Missions NM | 1,184 | 281 | 30 | 40 | 1,776 | 2,039 |
| San Antonio Missions NHP | 2,400 | 749 | 55 | 70 | 3,708 | 4,186 |
| San Francisco Maritime NHP | 5,828 | 1,570 | 83 | 103 | 8,602 | 9,627 |
| San Juan Island NHP | 696 | 186 | 14 | 17 | 966 | 1,047 |
| San Juan NHS | 3,386 | 834 | 87 | 107 | 4,877 | 5,483 |
| Santa Monica Mountains NRA | 6,027 | 1,726 | 123 | 149 | 9,017 | 10,039 |
| Saratoga NHP | 1,433 | 419 | 32 | 37 | 2,023 | 2,185 |
| Saugus Iron Works NHS | 660 | 174 | 15 | 18 | 1,000 | 1,124 |

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010 (continued)

| | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| Park Unit | Salary ($000's) | Payroll Benefits ($000's) | NPS Jobs | Total Jobs | Labor Income ($000's) | Value Added ($000's) |
| Scotts Bluff NM | 733 | 195 | 17 | 21 | 1,038 | 1,131 |
| Sequoia NP/ Kings Canyon NP | 17,027 | 4,274 | 358 | 431 | 23,986 | 26,354 |
| Shenandoah NP | 10,317 | 2,955 | 234 | 314 | 16,206 | 18,700 |
| Shiloh NMP | 1,655 | 431 | 39 | 47 | 2,310 | 2,546 |
| Sitka NHP | 1,173 | 310 | 20 | 26 | 1,729 | 1,952 |
| Sleeping Bear Dunes NL | 3,915 | 808 | 85 | 111 | 5,615 | 6,411 |
| Springfield Armory NHS | 864 | 173 | 18 | 23 | 1,271 | 1,457 |
| Statue of Liberty NM | 9,582 | 2,391 | 200 | 237 | 14,255 | 16,067 |
| Steamtown NHS | 3,499 | 988 | 48 | 71 | 5,327 | 5,986 |
| Stones River NB | 994 | 223 | 24 | 30 | 1,510 | 1,734 |
| Tallgrass Prairie NPRES | 610 | 147 | 13 | 15 | 800 | 848 |
| Thaddeus Kosciuszko NMEM | 115 | 38 | 3 | 4 | 188 | 215 |
| Theodore Roosevelt Birthplace NHS | 168 | 52 | 4 | 5 | 259 | 291 |
| Theodore Roosevelt Island | 75 | 23 | 2 | 2 | 112 | 123 |
| Theodore Roosevelt NP | 2,254 | 628 | 56 | 68 | 3,224 | 3,518 |
| Thomas Edison NHP | 1,915 | 446 | 31 | 39 | 2,780 | 3,133 |
| Thomas Stone NHS | 446 | 105 | 18 | 20 | 610 | 673 |
| Timpanogos Cave NM | 1,268 | 244 | 43 | 53 | 1,830 | 2,087 |
| Tonto NM | 723 | 219 | 15 | 20 | 1,159 | 1,342 |
| Tumacacori NHP | 962 | 273 | 18 | 22 | 1,390 | 1,530 |
| Tuskegee Airmen NHS | 304 | 87 | 7 | 8 | 425 | 463 |
| Tuskegee Institute NHS | 634 | 161 | 13 | 16 | 865 | 944 |
| Ulysses S. Grant NHS | 752 | 193 | 20 | 24 | 1,089 | 1,212 |
| Upper Delaware SRR | 1,943 | 517 | 33 | 40 | 2,696 | 2,956 |
| Valley Forge NHP | 4,672 | 1,248 | 67 | 95 | 7,326 | 8,433 |
| Vanderbilt Mansion NHS | 624 | 182 | 15 | 18 | 918 | 1,021 |
| Vicksburg NMP | 1,958 | 559 | 45 | 55 | 2,846 | 3,120 |
| Virgin Islands NP | 3,126 | 878 | 64 | 82 | 4,611 | 5,170 |
| Voyageurs NP | 3,473 | 932 | 65 | 84 | 4,999 | 5,486 |
| Walnut Canyon NM | 33 | 9 | 2 | 2 | 46 | 50 |
| Washita Battlefield NHS | 421 | 142 | 13 | 14 | 608 | 655 |
| Weir Farm NHS | 822 | 214 | 14 | 17 | 1,188 | 1,324 |
| Whiskeytown-Shasta-Trinity NRA | 3,952 | 1,100 | 89 | 109 | 5,765 | 6,357 |
| White House | 6,272 | 1,562 | 122 | 144 | 8,951 | 9,888 |
| White Sands NM | 1,158 | 324 | 30 | 34 | 1,582 | 1,697 |
| Whitman Mission NHS | 608 | 149 | 12 | 15 | 851 | 932 |
| William Howard Taft NHS | 495 | 138 | 10 | 12 | 746 | 834 |
| Wilson's Creek NB | 1,725 | 466 | 37 | 49 | 2,594 | 2,917 |
| Wind Cave NP | 3,334 | 868 | 85 | 101 | 4,815 | 5,341 |
| Wolf Trap Farm Park | 2,927 | 671 | 74 | 84 | 4,119 | 4,556 |

**Table A-2**. Payroll Impacts of National Park Units on Local Economies, FY 2010 (continued)

| Park Unit | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| | **Salary ($000's)** | **Payroll Benefits ($000's)** | **NPS Jobs** | **Total Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Women's Rights NHP | 904 | 256 | 16 | 20 | 1,289 | 1,411 |
| World War II Valor in the Pacific NM | 2,007 | 507 | 43 | 58 | 3,078 | 3,543 |
| Wrangell-St Elias NP & Pres | 3,964 | 814 | 63 | 84 | 5,610 | 6,366 |
| Wright Brothers NMEM | 207 | 46 | 6 | 7 | 294 | 334 |
| Wupatki NM | 2,378 | 648 | 50 | 59 | 3,326 | 3,609 |
| Yellowstone NP | 29,899 | 8,116 | 566 | 691 | 41,899 | 46,072 |
| Yosemite NP | 39,283 | 10,123 | 892 | 1005 | 53,199 | 57,156 |
| Yukon-Charley Rivers NPRES | 1,356 | 306 | 36 | 43 | 1,947 | 2,206 |
| Zion NP | 8,694 | 2,415 | 210 | 265 | 12,672 | 14,060 |

Notes: Jobs include part-time and full-time jobs with seasonal positions adjusted to an annual basis. NPS jobs, salary, and benefits are assigned to the unit where the employee's time was charged, which may differ from their duty station. Economic impacts include NPS payroll and jobs plus the induced effects of NPS employee spending of their wages and salaries in the local region. Jobs are rounded to the nearest job.

**Table A-3**. Payroll Impacts of National Park Units on Local Economies, Administrative Units and Parks without Visit Counts, FY 2010

| | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| **Park Unit** | **Salary ($000's)** | **Payroll Benefits ($000's)** | **NPS Jobs** | **Total Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Administration Team Coord, PGSO | 10,136 | 2,457 | 158 | 211 | 15,012 | 17,028 |
| African Burial Grounds | 703 | 136 | 18 | 22 | 981 | 1,104 |
| Ala Kahakai NHT | 226 | 65 | 3 | 4 | 320 | 348 |
| Alaska Regional Office | 5,014 | 1,125 | 70 | 97 | 7,148 | 8,030 |
| Alaska Support Office | 9,897 | 2,283 | 160 | 191 | 13,045 | 13,976 |
| American Memorial Park | 865 | 237 | 17 | 20 | 1,212 | 1,318 |
| Anacostia Park | 1 | 0 | 1 | 1 | 2 | 2 |
| Anchorage Interagency Visitors Center | 477 | 81 | 11 | 14 | 654 | 738 |
| Appalachian NST | 893 | 250 | 15 | 20 | 1,324 | 1,481 |
| Associate Reg Dir, Administration | 10,100 | 2,516 | 147 | 202 | 14,649 | 16,426 |
| Biological Resources Mgmt Division | 2,103 | 540 | 25 | 36 | 3,066 | 3,436 |
| Blackstone River Valley NHC | 732 | 200 | 12 | 16 | 1,079 | 1,208 |
| Boston Harbor Islands NRA | 853 | 186 | 20 | 25 | 1,211 | 1,361 |
| Boston Support Office | 889 | 224 | 10 | 14 | 1,292 | 1,448 |
| Cedar Creek and Belle Grove NHP | 309 | 69 | 4 | 6 | 452 | 513 |
| Center For Urban Ecology | 214 | 42 | 6 | 7 | 298 | 336 |
| Chesapeake Bay Program Office | 1,195 | 320 | 16 | 23 | 1,756 | 1,966 |
| Chihuahuan Desert Network | 312 | 92 | 5 | 7 | 466 | 521 |
| Columbia Cascades So | 6,229 | 1,604 | 85 | 117 | 9,319 | 10,558 |
| Denver Service Center | 19,679 | 4,962 | 508 | 617 | 28,602 | 32,065 |
| Ebey's Landing NHRES | 304 | 82 | 5 | 7 | 424 | 462 |
| Erie Canalway NHC | 220 | 69 | 4 | 5 | 317 | 344 |
| Fairbanks Interagency Visitors Center | 429 | 90 | 12 | 14 | 574 | 626 |
| Flagstaff Areas | 90 | 18 | 5 | 5 | 127 | 142 |
| FLETC (Fed Law Enforcement Tng Ctr) | 1,918 | 634 | 67 | 78 | 2,939 | 3,276 |
| Glen Echo Park | 198 | 55 | 6 | 7 | 278 | 302 |
| Gloria Dei Church NHS | 23 | 7 | 2 | 2 | 33 | 36 |
| Great Falls Park | 815 | 210 | 20 | 25 | 1,189 | 1,332 |
| Great Lakes Network | 761 | 230 | 16 | 20 | 1,144 | 1,278 |
| Greater Yellowstone Network | 432 | 107 | 8 | 10 | 627 | 703 |
| Harbor Parks | 618 | 167 | 10 | 13 | 909 | 1,018 |
| Harpers Ferry Center | 9,394 | 2,297 | 176 | 215 | 12,887 | 14,042 |
| Heartland Network | 516 | 169 | 10 | 13 | 789 | 880 |
| Historic Preservation Training Ctr (HPTC) | 262 | 73 | 9 | 10 | 387 | 433 |
| Horace Albright Training Ctr | 0 | 0 | 1 | 1 | 0 | 0 |
| Ice Age NST | 312 | 83 | 6 | 8 | 436 | 474 |
| Intermountain Nr-Pro | 948 | 255 | 18 | 23 | 1,394 | 1,561 |
| Intermountain Regional Office | 26,093 | 6,689 | 400 | 544 | 38,033 | 42,624 |
| Keweenaw NHP | 1,259 | 289 | 30 | 34 | 1,658 | 1,776 |
| Land Acquisition Project Office | 474 | 123 | 7 | 9 | 710 | 805 |

**Table A-3**. Payroll Impacts of National Park Units on Local Economies, Administrative Units and Parks without Visit Counts, FY 2010 (continued)

| | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| **Park Unit** | **Salary ($000's)** | **Payroll Benefits ($000's)** | **NPS Jobs** | **Total Jobs** | **Labor Income ($000's)** | **Value Added ($000's)** |
| Lewis & Clark NHT | 1,127 | 347 | 18 | 23 | 1,618 | 1,757 |
| Manhattan Sites | 1,118 | 273 | 20 | 26 | 1,616 | 1,813 |
| Mather Training Ctr | 0 | 0 | 0 | 0 | 0 | 0 |
| Midwest Archeological Center | 1,670 | 406 | 35 | 43 | 2,475 | 2,807 |
| Midwest Regional Office | 16,526 | 4,248 | 253 | 344 | 24,099 | 27,007 |
| Minidoka Internment NM | 194 | 52 | 6 | 7 | 271 | 294 |
| Mississippi NR&RA | 1,584 | 414 | 31 | 39 | 2,376 | 2,691 |
| Museum Resources Ctr | 441 | 102 | 7 | 10 | 632 | 710 |
| National Capital Regional Office | 3,671 | 838 | 62 | 83 | 5,247 | 5,893 |
| National Information Systems CNTR | 205 | 44 | 4 | 5 | 290 | 326 |
| National Information Technology CNTR | 186 | 10 | 16 | 17 | 233 | 266 |
| National Interagency Fire Center | 4,722 | 1,485 | 72 | 97 | 7,335 | 8,274 |
| National Mall | 4,991 | 1,093 | 142 | 169 | 7,088 | 7,966 |
| National Parks Of New York Harbor | 559 | 125 | 6 | 10 | 797 | 895 |
| National Trails System, Santa Fe | 1,360 | 392 | 19 | 26 | 2,076 | 2,347 |
| Natl Ctr For Rec & Conservation | 1,478 | 400 | 19 | 27 | 2,176 | 2,436 |
| NER Historic Architecture Program | 485 | 102 | 7 | 9 | 703 | 799 |
| North Country NST | 275 | 74 | 6 | 7 | 414 | 469 |
| Northeast Education Services Center | 13 | 2 | 1 | 1 | 19 | 21 |
| Northeast Museum Services Center | 703 | 189 | 9 | 13 | 1,060 | 1,200 |
| Northeast Regional Office | 24,922 | 6,270 | 342 | 473 | 37,140 | 42,095 |
| Northern Colorado Plateau Network | 744 | 217 | 18 | 22 | 1,112 | 1,243 |
| Northern Great Plains Network | 368 | 110 | 9 | 11 | 552 | 617 |
| NP Of American Samoa | 1,144 | 226 | 27 | 31 | 1,515 | 1,656 |
| Office Of The Chief Information Officer | 8,579 | 2,109 | 78 | 126 | 12,415 | 13,925 |
| Office Of The Director | 92,546 | 22,471 | 1,311 | 1,822 | 133,643 | 149,925 |
| Office Of Wyoming State Coordinator | 110 | 32 | 1 | 2 | 169 | 191 |
| Old Post Office Tower | 411 | 110 | 8 | 11 | 603 | 676 |
| Olmstead Center For Landscape Preservation | 685 | 193 | 14 | 18 | 1,041 | 1,178 |
| Overmountain Victory NHT | 88 | 18 | 2 | 2 | 126 | 144 |
| Pacific Island Support Office | 737 | 167 | 10 | 13 | 1,080 | 1,226 |
| Pacific West Regional Office | 8,975 | 2,143 | 158 | 205 | 13,260 | 15,044 |
| Parashant NM | 710 | 198 | 15 | 18 | 1,078 | 1,219 |
| Pinelands NRES (Interp Pgm) | 155 | 44 | 3 | 3 | 236 | 266 |
| Potomac Heritage NST | 125 | 38 | 3 | 3 | 188 | 210 |
| Presidio Of San Francisco | 8,279 | 2,508 | 138 | 184 | 12,452 | 13,909 |
| Rocky Mountain Network | 456 | 116 | 8 | 11 | 664 | 744 |
| Roosevelt-Vanderbilt Headquarters | 2,129 | 472 | 42 | 54 | 3,029 | 3,404 |
| Rosie the Riveter WW II Home Front NHP | 739 | 188 | 12 | 16 | 1,075 | 1,205 |

**Table A-3**. Payroll Impacts of National Park Units on Local Economies, Administrative Units and Parks without Visit Counts, FY 2010 (continued)

| Park Unit | Park Payroll | | | Impacts of Park Payroll | | |
|---|---|---|---|---|---|---|
| | Salary ($000's) | Payroll Benefits ($000's) | NPS Jobs | Total Jobs | Labor Income ($000's) | Value Added ($000's) |
| Saint Croix Island International HS | 182 | 32 | 5 | 6 | 258 | 294 |
| Salt River Bay NHP & Ecological PRES | 234 | 68 | 5 | 6 | 358 | 405 |
| Sand Creek Massacre NHS | 394 | 117 | 10 | 13 | 605 | 683 |
| SE Archeological Center | 1,385 | 371 | 32 | 40 | 2,086 | 2,361 |
| Selma To Montgomery NHT | 118 | 35 | 5 | 5 | 181 | 204 |
| Sonoran Desert Network | 596 | 164 | 14 | 18 | 880 | 984 |
| Southeast Regional Office | 24,996 | 6,162 | 369 | 500 | 37,123 | 42,094 |
| Southern Arizona Group | 708 | 201 | 13 | 16 | 1,078 | 1,219 |
| Southern Colorado Plateau Network | 716 | 226 | 12 | 16 | 1,086 | 1,212 |
| Southern Plains Network | 269 | 61 | 5 | 7 | 384 | 432 |
| Spanish Colonial Research Center | 99 | 32 | 2 | 3 | 155 | 174 |
| Strategic Planning Division | 180 | 50 | 2 | 3 | 266 | 297 |
| United States Park Police | 69,452 | 24,944 | 1,058 | 1,442 | 108,373 | 120,592 |
| Virgin Islands Coral Reef NM | 210 | 74 | 8 | 9 | 334 | 375 |
| Washington Training Ctr | 9 | 2 | 1 | 1 | 13 | 15 |
| Western Archeological & Conservation Center | 700 | 171 | 12 | 16 | 1,038 | 1,177 |
| Western Arctic National Parklands | 1,917 | 446 | 32 | 42 | 2,821 | 3,202 |
| Yucca House NM | 61 | 23 | 2 | 2 | 99 | 111 |

Notes: Jobs include part-time and full-time jobs with seasonal positions adjusted to an annual basis. NPS jobs, salary, and benefits are assigned to the unit where the employee's time was charged, which may differ from their duty station. Economic impacts include NPS payroll and jobs plus the induced effects of NPS employee spending of their wages and salaries in the local region. Jobs are rounded to the nearest job.

**Table A-4**. Impacts of NPS Visitor Spending and Payroll on Local Economies by State, 2010

| State | Recreation Visits | Non-Local Visitor Spending ($000's) | Jobs from Non-Local Visitor Spending | Payroll-related Jobs | Total Jobs |
|---|---|---|---|---|---|
| Alabama | 781,550 | 19,043 | 311 | 92 | 403 |
| Alaska | 2,274,781 | 208,185 | 2,637 | 1,061 | 3,698 |
| American Samoa | 0 | 0 | | 52 | 52 |
| Arizona | 10,546,150 | 671,467 | 9,661 | 1,351 | 11,012 |
| Arkansas | 3,125,664 | 137,996 | 2,216 | 302 | 2,518 |
| California | 34,633,664 | 1,076,998 | 13,822 | 4,022 | 17,844 |
| Colorado | 5,631,244 | 292,721 | 4,345 | 2,021 | 6,366 |
| Connecticut | 19,313 | 1,162 | 13 | 17 | 30 |
| District of Columbia | 33,140,005 | 908,844 | 10,875 | 5,481 | 16,356 |
| Florida | 9,222,981 | 513,999 | 7,608 | 922 | 8,530 |
| Georgia | 6,776,556 | 214,277 | 3,036 | 865 | 3,901 |
| Guam | 219,349 | 7,109 | 85 | 0 | 85 |
| Hawaii | 4,493,123 | 235,974 | 3,195 | 545 | 3,740 |
| Idaho | 530,977 | 19,661 | 298 | 192 | 490 |
| Illinois | 354,125 | 18,178 | 285 | 52 | 336 |
| Indiana | 2,395,485 | 55,805 | 847 | 203 | 1,050 |
| Iowa | 222,295 | 11,028 | 192 | 67 | 258 |
| Kansas | 100,361 | 4,429 | 76 | 83 | 159 |
| Kentucky | 1,797,894 | 86,016 | 1,409 | 311 | 1,721 |
| Louisiana | 496,329 | 22,978 | 332 | 111 | 443 |
| Maine | 2,504,208 | 183,491 | 3,147 | 190 | 3,337 |
| Maryland | 3,541,570 | 164,885 | 2,198 | 386 | 2,583 |
| Massachusetts | 9,913,501 | 393,235 | 5,297 | 671 | 5,968 |
| Michigan | 1,796,006 | 139,901 | 2,438 | 256 | 2,694 |
| Minnesota | 540,195 | 29,690 | 486 | 196 | 682 |
| Mississippi | 6,588,026 | 79,329 | 1,171 | 260 | 1,431 |
| Missouri | 4,140,544 | 155,992 | 2,427 | 474 | 2,900 |
| Montana | 4,584,011 | 291,405 | 4,390 | 804 | 5,194 |
| Nebraska | 290,323 | 9,538 | 179 | 145 | 323 |
| Nevada | 5,399,439 | 166,479 | 1,894 | 376 | 2,269 |
| New Hampshire | 30,941 | 1,076 | 17 | 18 | 35 |
| New Jersey | 5,858,443 | 121,506 | 1,848 | 278 | 2,127 |
| New Mexico | 1,657,550 | 65,411 | 976 | 545 | 1,521 |
| New York | 17,389,242 | 362,301 | 4,256 | 1,039 | 5,295 |
| North Carolina | 17,093,464 | 701,499 | 10,404 | 669 | 11,073 |
| North Dakota | 659,927 | 29,753 | 531 | 102 | 633 |
| Ohio | 2,738,275 | 53,289 | 858 | 304 | 1,163 |
| Oklahoma | 1,266,189 | 13,735 | 182 | 105 | 287 |
| Oregon | 888,358 | 53,059 | 831 | 222 | 1,053 |
| Pennsylvania | 8,970,475 | 314,246 | 4,858 | 1,270 | 6,127 |
| Puerto Rico | 1,105,252 | 51,169 | 781 | 107 | 888 |
| Rhode Island | 51,559 | 3,103 | 49 | 12 | 61 |
| South Carolina | 1,529,172 | 42,799 | 679 | 125 | 804 |
| South Dakota | 4,199,267 | 162,442 | 2,758 | 346 | 3,104 |
| Tennessee | 7,898,557 | 519,702 | 7,538 | 445 | 7,983 |
| Texas | 5,495,156 | 215,964 | 3,312 | 674 | 3,986 |
| Utah | 8,975,525 | 611,714 | 9,267 | 904 | 10,171 |

**Table A-4**. Impacts of NPS Visitor Spending and Payroll on Local Economies by State, 2010 (continued)

| State | Recreation Visits | Non-Local Visitor Spending ($000's) | Jobs from Non-Local Visitor Spending | Payroll-related Jobs | Total Jobs |
|---|---|---|---|---|---|
| Vermont | 31,209 | 1,445 | 21 | 33 | 54 |
| Virgin Islands | 638,094 | 66,680 | 1,169 | 116 | 1,285 |
| Virginia | 22,708,338 | 505,962 | 7,294 | 1,264 | 8,558 |
| Washington | 7,281,785 | 242,467 | 3,611 | 950 | 4,560 |
| West Virginia | 1,811,722 | 59,713 | 785 | 488 | 1,273 |
| Wisconsin | 251,145 | 19,415 | 327 | 100 | 427 |
| Wyoming | 6,307,997 | 610,634 | 9,059 | 786 | 9,845 |
| Total | 280,897,309 | 10,948,899 | 156,279 | 32,407 | 188,686 |

Notes: Payroll-related jobs include NPS jobs and the induced effects of the NPS payroll on the local economy, covering parks with visit counts (Table A-2) as well as administrative units and parks without visit counts (Table A-3). Total job impacts include those supported by non-local visitor spending and the NPS payroll. For 20 parks with property in more than one state, activity is allocated using the proportions in Table A-6.

**Table A-5**. Impacts of NPS Visitor Spending and Payroll on Local Economies by Region, 2010

| Region | Recreation Visits | Non-Local Spending ($ Millions) | Jobs from Non-Local Visitor Spending | Payroll-related Jobs | Total Jobs |
|---|---|---|---|---|---|
| Alaska | 2,274,781 | 208 | 2,637 | 1,061 | 3,698 |
| Harpers Ferry | | 0 | | 215 | 215 |
| Intermountain | 42,648,861 | 2,717 | 40,554 | 7,090 | 47,644 |
| Midwest | 20,804,846 | 827 | 13,610 | 2,627 | 16,237 |
| National Capital | 45,271,135 | 1,119 | 13,445 | 2,064 | 15,509 |
| Northeast | 55,118,574 | 1,795 | 25,642 | 4,569 | 30,211 |
| Pacific West | 55,261,655 | 1,857 | 24,373 | 6,458 | 30,831 |
| Southeast | 59,517,457 | 2,425 | 36,018 | 4,143 | 40,161 |
| Washington Office | | | | 4,179 | 4,179 |
| **Total** | 280,897,309 | 10,949 | 156,279 | 32,407 | 188,686 |

Notes: Payroll-related jobs include NPS jobs and the induced effects of the NPS payroll on the local economy, covering parks with visit counts (Table A-2) as well as administrative units and parks without visit counts (Table A-3). Total job impacts include those supported by non-local visitor spending and the NPS payroll.

**Table A-6**. Allocations to States for Multi-state Parks

| Park | State | Share |
|---|---|---|
| Assateague Island NS | MD | 33% |
| Assateague Island NS | VA | 67% |
| Bighorn Canyon NRA | WY | 46% |
| Bighorn Canyon NRA | MT | 54% |
| Big South Fork NRRA | KY | 41% |
| Big South Fork NRRA | TN | 59% |
| Blue Ridge Parkway | VA | 38% |
| Blue Ridge Parkway | NC | 62% |
| Chickamauga & Chattanooga NMP | GA | 50% |
| Chickamauga & Chattanooga NMP | TN | 50% |
| Chesapeake & Ohio Canal NHP | WV | 6% |
| Chesapeake & Ohio Canal NHP | MD | 9% |
| Chesapeake & Ohio Canal NHP | DC | 85% |
| Cumberland Gap NHP | KY | 93% |
| Cumberland Gap NHP | VA | 7% |
| Delaware Water Gap NRA | PA | 29% |
| Delaware Water Gap NRA | NJ | 71% |
| Dinosaur NM | UT | 26% |
| Dinosaur NM | CO | 74% |
| Gateway NRA | NJ | 20% |
| Gateway NRA | NY | 80% |
| Glen Canyon NRA | AZ | 8% |
| Glen Canyon NRA | UT | 92% |
| Great Smoky Mountains NP | NC | 44% |
| Great Smoky Mountains NP | TN | 56% |
| Gulf Islands Nat Seashore | MS | 25% |
| Gulf Islands Nat Seashore | FL | 75% |
| Hovenweep NM | CO | 44% |
| Hovenweep NM | UT | 56% |
| Lake Mead NRA | AZ | 25% |
| Lake Mead NRA | NV | 75% |
| Natchez Trace Parkway | AL | 7% |
| Natchez Trace Parkway | TN | 13% |
| Natchez Trace Parkway | MS | 80% |
| National capital Parks East | MD | 10% |
| National capital Parks East | DC | 90% |
| Saint Croix Nat scenic river | MN | 50% |
| Saint Croix Nat scenic river | WI | 50% |
| Upper Delaware SRR | NY | 50% |
| Upper Delaware SRR | PA | 50% |
| Yellowstone NP | WY | 49% |
| Yellowstone NP | MT | 51% |

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 999/112136, December 2011

**National Park Service**
**U.S. Department of the Interior**

**Natural Resource Stewardship and Science**
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

**EXPERIENCE YOUR AMERICA ™**

# EXHIBIT 8

# Table 1215. **National Park System—Summary: 1990 to 2008**

[**For year ending September 30, except as noted. (986 represents $986,000,000).** Includes data for five areas in Puerto Rico and Virgin Islands, one area in American Samoa, and one area in Guam]

| Item | 1990 | 1995 | 2000 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| Finances (mil. dol.): [1] | | | | | | | | |
| Expenditures reported | 986 | 1,445 | 1,833 | 2,371 | 2,451 | 2,463 | 2,412 | 2,614 |
| Salaries and wages | 459 | 633 | 799 | 956 | 984 | 998 | 1,005 | 1,066 |
| Improvements, maintenance | 160 | 234 | 299 | 332 | 361 | 389 | 381 | 428 |
| Construction | 109 | 192 | 215 | 354 | 381 | 300 | 280 | 303 |
| Other | 259 | 386 | 520 | 729 | 725 | 776 | 746 | 817 |
| Funds available | 1,506 | 2,225 | 3,316 | 4,087 | 4,218 | 4,242 | 4,266 | 4,537 |
| Appropriations | 1,053 | 1,325 | 1,881 | 2,388 | 2,425 | 2,450 | 2,484 | 2,636 |
| Other [2] | 453 | 900 | 1,435 | 1,699 | 1,793 | 1,792 | 1,782 | 1,901 |
| Revenue from operations | 79 | 106 | 234 | 264 | 286 | 308 | 346 | 404 |
| Recreation visits (millions): [3] | | | | | | | | |
| All areas | 258.7 | 269.6 | 285.9 | 276.9 | 273.5 | 272.6 | 275.6 | 274.9 |
| National parks [4] | 57.7 | 64.8 | 66.1 | 63.8 | 63.5 | 60.4 | 62.3 | 61.2 |
| National monuments | 23.9 | 23.5 | 23.8 | 19.8 | 20.9 | 19.6 | 19.7 | 20.2 |
| National historical, commemorative, archaeological [5] | 57.5 | 56.9 | 72.2 | 77.0 | 74.9 | 73.6 | 75.1 | 76.2 |
| National parkways | 29.1 | 31.3 | 34.0 | 31.7 | 31.7 | 32.6 | 31.1 | 30.2 |
| National recreation areas [4] | 47.2 | 53.7 | 50.0 | 46.6 | 46.8 | 47.8 | 48.9 | 49.6 |
| National seashores and lakeshores | 23.3 | 22.5 | 22.5 | 21.3 | 21.7 | 19.6 | 19.9 | 19.3 |
| National Capital Parks | 7.5 | 5.5 | 5.4 | 4.7 | 4.3 | 6.2 | 4.9 | 5.1 |
| Recreation overnight stays (millions) | 17.6 | 16.8 | 15.4 | 13.7 | 13.5 | 13.2 | 13.8 | 13.7 |
| In commercial lodgings | 3.9 | 3.8 | 3.7 | 3.5 | 3.4 | 3.4 | 3.6 | 3.6 |
| In Park Service campgrounds | 7.9 | 7.1 | 5.9 | 5.4 | 5.2 | 5.0 | 5.1 | 5.0 |
| In backcountry | 1.7 | 2.2 | 1.9 | 1.7 | 1.7 | 1.7 | 1.7 | 1.8 |
| Other | 4.2 | 3.7 | 3.8 | 3.1 | 3.2 | 3.1 | 3.4 | 3.3 |
| Land (1,000 acres): [6, 7] | | | | | | | | |
| Total | 76,362 | 77,355 | 78,153 | 79,023 | 79,048 | 78,810 | 78,845 | 78,859 |
| Parks | 46,089 | 49,307 | 49,785 | 49,892 | 49,910 | 49,912 | 49,911 | 49,916 |
| Recreation areas | 3,344 | 3,353 | 3,388 | 3,391 | 3,391 | 3,391 | 3,413 | 3,413 |
| Other | 26,929 | 24,695 | 24,980 | 25,740 | 25,747 | 25,507 | 25,521 | 25,530 |
| Acquisition, net | 21 | 27 | 186 | 12 | 17 | 16 | 23 | 7 |

[1] Financial data are those associated with the National Park System. Certain other functions of the National Park Service (principally the activities absorbed from the former Heritage Conservation and Recreation Service in 1981) are excluded. [2] Includes funds carried over from prior years. [3] For calendar year. Includes other areas, not shown separately. [4] For 1990, combined data for North Cascades National Park and two adjacent National Recreation Areas are included in National Parks total. [5] Includes military areas. [6] Federal land only, as of Dec. 31. Federal land acreages, in addition to National Park Service administered lands, also include lands within national park system area boundaries but under the administration of other agencies. Year-to-year changes in the federal lands figures includes changes in the acreages of these other lands and hence often differ from "net acquisition." [7] The decrease in the 2006 land total reflects corrected acreage by the Bureau of Land Management, not by the National Park Service lands.

Source: U.S. National Park Service, *National Park Statistical Abstract,* annual and unpublished data. See also <http://www2.nature.nps.gov/stats/>.

# EXHIBIT 9

# The U.S. National Park System

## *An Economic Asset at Risk*

Hardner & Gullison

**Prepared for:**
National Parks Conservation Association

**Prepared by:**
Jared Hardner
Bruce McKenney

**Date:**
May 30, 2006

# Acknowledgements

The authors extend their gratitude to the many experts in academia, non-governmental organizations, private consulting firms, and the National Park Service that provided guidance in the development of this report. Their names, too numerous to list here, can be found in the appendix to this report. A special thanks for reviewing the draft report go to Dr. Bruce Peacock of the National Park Service, Dr. Daniel Stynes of Michigan State University, and Dr. John Loomis of Colorado State University.

# About Hardner & Gullison Associates, LLC

Hardner & Gullison Associates, LLC is a private consulting firm that provides technical assistance in the field of conservation to foundations, conservation groups, governments, and corporations. Its work includes economic analysis, conservation finance, program evaluation, project design and implementation, and corporate environmental management. Members of the firm include among their past and present clients the World Bank, Inter-American Development Bank, Asian Development Bank, U.S. Agency for International Development, The Nature Conservancy, World Wildlife Fund, Conservation International, National Parks Conservation Association, Environmental Defense, National Fish and Wildlife Foundation, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, BP, Shell Oil Company, Compañía Minera Antamina, among others. For more information, please visit www.hg-llc.com.

# Contents

**Executive Summary** 5

**Chapter 1: Introduction** 7

**Chapter 2: Cost-Benefit Analysis of National Parks** 9
Economic Benefits of National Parks 9
Costs of National Park Service 12
Cost-Benefit Comparison 12
Cost-Benefit Analysis of the NPS Budget Shortfall 13
Conclusion 15

**Chapter 3: Economic Impacts of National Parks** 17
Economic Impact Estimates: System-Wide and Case Studies 17
Opportunities for Refining and Extending Impact Estimates 18
Conclusion 19

**Chapter 4: Economic Growth and National Parks** 21
Measuring Economic Growth 21
Amenity-Driven Economic Growth 21
Economic Growth and National Parks 22
Smart Growth 23
Conclusion 24

**Chapter 5: Case Studies** 25
Acadia National Park 27
Apostle Islands National Seashore 28
Biscayne National Park 29
Denali National Park and Preserve 30
Fort Sumter National Monument 31
Gettysburg National Military Park 32
Joshua Tree National Park 33
Point Reyes National Seashore 34
Rocky Mountain National Park 35
Sequoia and Kings Canyon National Parks 36
Shenandoah National Park 37
Zion National Park 38

**Chapter 6: Next Steps** 39

**References** 41

**Appendix: Key Project Steps and Sources** 43

# Executive Summary

**The U.S. National Park System is an economic asset at risk.** The park system generates at least four dollars in value to the public for every tax dollar invested in its annual budget. Yet, every year the parks suffer an operating shortfall of $800 million, in addition to a massive multi-billion dollar maintenance backlog. As a result, the fiscal crisis confronting the national parks continues to deepen and important park functions go without, park infrastructure decays, natural ecosystems are overrun with exotic species, historical treasures are inadequately preserved, and public safety is jeopardized.

The U.S. Congress established and maintains the National Park System to conserve our nation's most significant lands and landmarks. Yet, the U.S. Congress is jeopardizing this valuable asset by not adequately funding the National Park Service. Although the full value of the park system evades quantification, this report presents hard economic evidence that national parks generate tremendous value to the public.

- National parks generate more than four dollars in value to the public for every tax dollar invested.
- National parks support $13.3 billion of local private-sector economic activity and 267,000 private-sector jobs.
- National parks attract businesses and individuals to the local area, resulting in economic growth in areas near parks that is an average of 1 percent per year greater than statewide rates over the past three decades.
- The benefits of national parks are many and extend well beyond economic values.

In developing the study we conducted an extensive literature review and interviewed 30 experts from academia, the National Park Service and other governmental agencies, non-governmental organizations, and the private sector to gain their perspective on the economic role of the National Park System. We determined that capturing the economic importance of national parks requires using three different approaches, each of which illuminates a different perspective. The results are not additive, but rather provide a view on the significance of parks to national, regional, and local stakeholders.

First we use cost-benefit analysis to examine the national economic benefits of the park system relative to its cost to taxpayers. Second, we analyze the economic impact of national parks to the communities that surround them. And finally, we measure economic growth in the regions around parks. All analyses point to the same conclusion, the U.S. National Park System is an asset of tremendous economic value at the national, regional, and local level. Failure to properly manage our parks puts this public asset in jeopardy.

### Cost-Benefit Analysis

**The National Park System generates at *least* four dollars in value to the public for every tax dollar appropriated for its budget.** This report uses cost-benefit analysis to measure the economic value generated by national parks, and to compare that value with the cost of running the National Park Service.

Cost-benefit analysis is a standard approach used by the Federal Government, institutionalized by an executive order under President Ronald Reagan in 1981, to assess whether a government regulation or expenditure generates value for U.S. citizens. According to public finance theory, government should raise the funds necessary to invest in projects that generate value in excess of their cost.

For this analysis we draw upon a database of approximately one thousand estimates of the economic value derived from visitation to national parks and wilderness areas in the United States (Kaval and Loomis 2003). The analysis shows that the National Park System generates approximately four times the value ($10.1 billion) of its cost to taxpayers ($2.6 billion). We also perform a series of 12 case studies of individual parks within the system and find that sites such as Acadia National Park and Point Reyes National Seashore generate over 14 times the economic value to the public compared to their annual budgets. In none of our case studies do annual budgetary expenditures exceed the economic benefits generated for the public.

**And these value estimates are conservative** – because of limitations in valuation methods and data, we only consider the benefits derived from direct recreational use by park visitors. Parks generate a wide range of other values not quantified in this report. They include *use values* such as: ecosystem services like provision of clean air and water; biodiversity conservation; scientific research; education; and cultural and spiritual values. They also include *passive-use values* such as the comfort of knowledge that our nation's natural and historical treasures are conserved for public enjoyment today and for

**COST-BENEFIT RATIO OF NPS**

| *NPS Economic Benefits* | *NPS Budget* | *Cost-Benefit Ratio* | *Justified Public Expenditure (Benefits/Cost > 1)?* |
|---|---|---|---|
| >$10.1 Billion | $2.6 Billion | >3.9 | YES |

| TABLE 7: NPS SYSTEM-WIDE LOCAL ECONOMIC IMPACT ESTIMATES | | | | |
|---|---|---|---|---|
| *Total annual visitor spending ($billion)* | *Sales ($billion)* | *Personal income ($billion)* | *Jobs* | *Value Added ($billion)* |
| 11.3* | 13.3 | 4.8 | 267,000 | 7.5 |

* Public sector (NPS) spending adds $2-3 billion to this estimate for a total of about $14 billion in annual direct spending.
Source: Stynes and Sun 2003
Note: All figures adjusted to 2004 dollars.

future generations. **Considering the entire suite of economic benefits generated by our national parks, the National Park System generates value likely many times greater than this estimate.**

### Economic Impact Analysis

**The park system is responsible for $13.3 billion of local *private-sector* economic activity, supporting 267,000 *private-sector* jobs.** This reflects the *local* economic impacts of park-related tourism.

Economic impact analysis provides an estimate of the level of economic activity in terms of sales, jobs, wages and profits attributable to a public investment. In the case of national parks, visitors spend money on travel, lodging, food, and other goods and services, all of which can be quantified in an impact analysis. In fact, not only are these direct transactions quantifiable, so are the indirect impacts as tourist expenditures ripple through the economy. In other words, income earned in the tourism sector is spent locally on other goods and services, generating more sales, jobs, income and profits.

This report summarizes analyses performed by researchers at Michigan State University for the National Park Service using the *Money Generation Model 2 (MGM2)*. According to this work, national park visitors spend $11.3 billion in areas local to national parks, resulting in $13.3 billion in economic activity, 267,000 jobs, and $7.5 billion in wages and profits.

The economic impacts estimated by MGM2 are conservative. They exclude expenditures made outside of a 50-100 mile radius of national parks, including among other things airfare and other modes of travel from afar as well as equipment and other goods purchased for visits to parks. **Considering all spending for visits to national parks could increase impact estimates by two to four times those provided by MGM2.**

### Economic Growth Analysis

**National parks play a major role in attracting businesses and individuals to the local area resulting in economic growth that outpaces areas without parks.** This report compares various indices of economic growth in areas near parks to all other areas.

Economic growth shows the cumulative impact of economic activity, and can be measured in a variety of ways, including changes in population, number of jobs, per capita income, and earnings per job. Comparing these indices for areas near parks and areas far from parks allows us to draw conclusions about the role of parks as engines of economic growth.

Case analyses of park areas conducted for this report indicate population, employment, and per capita income have exceeded statewide rates by an average of 1 percent per year over the past three decades. What's even more compelling is that this growth can only partly be explained by tourism–the majority is driven by individuals and companies unrelated to the tourism sector that are likely drawn to the area because of its natural amenities.

In order to conduct this analysis, we rely on a database developed by the Sonoran Institute for the US Bureau of Land Management. The database, called the *Economic Profile System (EPS),* provides county-level economic and demographic data from multiple public sources spanning the last thirty years.

The data clearly show that growth rates in counties around parks outpace statewide averages. This is further proof that national parks are of economic significance, if not engines of economic growth. Yet, failure to properly manage parks could result in the deterioration of the very amenities that drive this growth. Parks must be fully funded to conserve the natural attributes the National Park Service is mandated to protect.

### Conclusions

The estimated required budget of the National Park System is $3.4 billion per year, plus the investment required to eliminate the maintenance backlog estimated at between $4.5 and $9.7 billion. Annual appropriations of $2.6 billion for national parks fall short by $800 million, before considering the maintenance backlog. Budget shortfalls are undermining the park system, a valuable economic asset and national treasure. Given the economic analysis, **cutting park budgets cannot be described as prudent fiscal belt-tightening. Instead, it is undermining a public economic asset that will result in negative economic repercussions for U.S. citizens.**

This report provides a clear exposition on the economic value, impact, and growth effects of the National Park System. The estimates in this report are intentionally conservative to ensure that advocates and critics alike are presented with reliable and concrete data for informed public policy debate.

Lastly, it is important to emphasize that this report provides an economic perspective only. The merits of the National Park System and the reasons to properly fund it are myriad and transcend a strictly numerical analysis. This report provides just one approach to examining its importance.

# Chapter 1: Introduction

The U.S National Park System protects our country's natural and historic treasures, conserving and managing key sites of our nation's heritage such as Yellowstone National Park and Gettysburg National Military Park. It is managed by the National Park Service (NPS), which was created by an act of congress in 1916 "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." Today's park system includes 390 units covering more than 83 million acres.

This report examines the economic significance of the park system, including the *economic benefits* generated by the parks, the *economic impacts* of park visitation, and the *economic growth* patterns associated with parks. Many researchers and government analysts have studied various aspects of the system's role in the economy, but here we attempt to synthesize those approaches into a unified portrait. Different analytic approaches allow us to examine the economic significance of the national park system from perspectives relevant to a range of stakeholders (Table 1).

- *Economic Benefit* is a national concern – it measures the total value that people derive from the national park system through direct and passive use.

- *Economic Impact* is a local concern – it measures park visitors' spending and the effects it has on a town or county's output, employment, and income.

- *Economic Growth* is a local and regional concern – it highlights trends occurring as a result of economic activity associated with proximity to parks. Such economic activity extends beyond tourism to include all economic activity attracted to an area by the natural amenities provided by the park.

The three measures of economic significance are not directly comparable, nor can one sum them to generate a single number that represents the economic importance of the park system. Instead, we need to evaluate each independently, as we do in the following chapters of this report.

Our analysis demonstrates that each measure of economic significance reflects quite positively on the national park system. Adjusting all figures to the year 2004:

- The economic benefits of the park system are at least $10.1 billion per year, and likely much greater;

- The total economic impact of visitor spending in areas surrounding parks was $13.3 billion in sales, creating 267,000 jobs and $7.5 billion in value added (wages, rents, and business profits); and,

- Economic growth in counties around national parks is generally faster than other counties in the same states.

We also show that federal spending on national parks generates a fourfold increase in value for the nation, and that proposed budget increases for the system clearly satisfy economic scrutiny. In fact, current threats to national parks resulting from budgetary shortfalls may likely cause significant losses in economic benefits to the nation.

In order to illustrate these points more fully, we present 12 site-level case studies, representing a diversity of geographic locations, types of sites, levels of visitation, proximity to population centers, and levels of funding. The cases are:

- Acadia National Park
- Apostle Islands National Lakeshore
- Biscayne National Park
- Denali National Park and Preserve
- Fort Sumter National Monument
- Gettysburg National Military Park
- Joshua Tree National Park
- Point Reyes National Seashore
- Rocky Mountain National Park
- Sequoia and Kings Canyon National Parks

**Table 1:**
**Measures of Economic SIGNIFICANCE**
**oF the U.S. National Park System**

| *Analytic Approach* | *Indicators* | *Geographic Concern* |
|---|---|---|
| Economic Benefits | Value derived from *direct use*, such as recreation, or *passive use*, such as the value of knowing national treasures are protected and will be passed on to future generations | National |
| Economic Impact | Sales, jobs, personal income, and value added generated from visitor spending | Local |
| Economic Growth | Trends in population, per capita income, employment, wages, housing costs, and the distributional effects throughout the economy | Local and Regional |

- Shenandoah National Park
- Zion National Park

For each of the twelve cases, we analyze economic benefits, impacts, and growth patterns. Results of the case studies appear throughout the report, and are summarized on a site-by-site basis in Chapter 5.

The report attempts to pull together a broad body of economic research and analysis that has been conducted over the years. Many of the researchers behind that work have provided input to shape this report. Building on this expansive base of expertise, our synthesis of the economic importance of the national park system demonstrates quite clearly that the parks, seashores, historic and other sites in the system are national assets of tremendous value, and merit the budgetary consideration necessary to protect and maintain them.

# Chapter 2: Cost-Benefit Analysis of National Parks

*"Although cost-benefit analysis is surely an imperfect tool, it is the only analytic framework available for making consistent decisions. Forbidding cost-benefit analysis amounts to outlawing sensible decision making."*

Harvey Rosen, Ph.D. in *Public Finance* (1988)
Professor of Economics and Business Policy, Princeton University
Member & Chairman, President's Council of Economic Advisers (2003-2005)

*Social cost-benefit analysis* is an analytic approach used by governments to determine whether the net economic benefits to society of a public-sector program are greater than the costs. Cost-benefit analysis became a standard tool for decision making in the U.S. Government during the Johnson administration, entitled the *Planning Programming Budget System*. It was further institutionalized in 1981 when President Reagan issued an executive order that all new federal regulations needed to pass a cost-benefit test. As a result cost-benefit analysis has become a standard analysis in the U.S. Government, with regular guidance provided by the White House Office of Management and Budget (see Box A).

In the case of the national parks, cost-benefit analysis can show whether the cost of maintaining the system is merited by the value it generates for the U.S. public. Fundamentally, most U.S. citizens view the management of sites like the Statue of Liberty and Yellowstone as an unquestionable responsibility of the federal government. Discussion of cost-benefit analysis is typically stopped short by the assertion that such national treasures are "priceless" and analysis of their economic value is misguided.

Nevertheless, NPS finds itself short of funding to perform the management functions necessary to maintain its sites, suggesting the federal government has underestimated their public value. Of course, the political challenge to acquiring funding needed by NPS is complex, so in an effort to place these budget needs into a clear analytic framework for public decision makers we provide a cost-benefit analysis that quantifies the economic implications of budgetary spending on the national park system. Such an approach puts budget allocation decisions to the same test as many other federal projects, programs, and regulations ensuring fair consideration of NPS needs in budgetary debates.

### Economic Benefits of National Parks

The types of economic benefits associated with national parks have been studied extensively. Economists have categorized the benefits flowing from parks into two broad categories: *use* and *passive-use* (Table 2). Use benefits include the value visitors place on recreation, scientific and educational uses, ecological services such as the provision of clean water to communities and habitat for a number of species that may have economic effects (e.g. reproduction of species hunted offsite, insects necessary for pollination, etc.), conservation of biodiversity for its genetic and intrinsic value, as well as the cultural and spiritual values of many sites. Passive-use benefits include the value individuals place on the option to use a site in the future, or the mere knowledge that a site is protected (*existence value*) and will be so for generations to come (*bequest value*).

*Consumer surplus* is the technical term used for the difference between the value an individual places on an economic benefit and the cost they incur to enjoy it. In other words, a visitor may pay $70 to travel to Acadia National Park, but enjoys $100 in perceived value (also known as *willingness-to-pay*) from the experience of birdwatching while in the park. The consumer surplus for that visit is $30. It is possible to add up the consumer surplus of all visitors to a park to determine the total consumer surplus derived from public visitation. This is also known as *social economic benefit*.

**TABLE 2: ECONOMIC BENEFITS OF NATIONAL PARKS**

| | |
|---|---|
| Use Values | Recreation |
| | Subsistence (Alaskan parks only) |
| | Offsite Benefits (hunting, scenic viewsheds) |
| | Ecosystem services (water quality, habitat) |
| | Biodiversity (intrinsic value, genetic value) |
| | Science |
| | Education |
| | Cultural |
| | Spiritual |
| Passive-Use Values | Option |
| | Existence |
| | Bequest |

**Box A: Guidance for Cost-Benefit Analysis from White House Office of Management and Budget (OMB)**

The White House Office of Management and Budget (OMB) provides updated guidance on the use of cost-benefit analysis in OMB Circular A-4, September 17, 2003. Following is an excerpt from the circular.

*The Need for Analysis of Proposed Regulatory Actions*

A good regulatory analysis is designed to inform the public and other parts of the Government (as well as the agency conducting the analysis) of the effects of alternative actions. Regulatory analysis sometimes will show that a proposed action is misguided, but it can also demonstrate that well-conceived actions are reasonable and justified.

Benefit-cost analysis is a primary tool used for regulatory analysis. Where all benefits and costs can be quantified and expressed in monetary units, benefit-cost analysis provides decision makers with a clear indication of the most efficient alternative, that is, the alternative that generates the largest net benefits to society (ignoring distributional effects). This is useful information for decision makers and the public to receive, even when economic efficiency is not the only or the overriding public policy objective.

It will not always be possible to express in monetary units all of the important benefits and costs. When it is not, the most efficient alternative will not necessarily be the one with the largest quantified and monetized net-benefit estimate. In such cases, you should exercise professional judgment in determining how important the non-quantified benefits or costs may be in the context of the overall analysis. If the non-quantified benefits or costs are likely to be important, you should carry out a "threshold" analysis to evaluate their significance. Threshold or "break-even" analysis answers the question, "How small could the value of the non-quantified benefits be (or how large would the value of the non-quantified costs need to be) before the rule would yield zero net benefits?" In addition to threshold analysis you should indicate, where possible, which non-quantified effects are most important and why.

*Key Elements of a Regulatory Analysis*

A good regulatory analysis should include the following three basic elements: (1) a statement of the need for the proposed action, (2) an examination of alternative approaches, and (3) an evaluation of the benefits and costs – quantitative and qualitative – of the proposed action and the main alternatives identified by the analysis.

To evaluate properly the benefits and costs of regulations and their alternatives, you will need to do the following:

- Explain how the actions required by the rule are linked to the expected benefits. For example, indicate how additional safety equipment will reduce safety risks. A similar analysis should be done for each of the alternatives.
- Identify a baseline. Benefits and costs are defined in comparison with a clearly stated alternative. This normally will be a "no action" baseline: what the world will be like if the proposed rule is not adopted. Comparisons to a "next best" alternative are also especially useful.
- Identify the expected undesirable side-effects and ancillary benefits of the proposed regulatory action and the alternatives. These should be added to the direct benefits and costs as appropriate.

With this information, you should be able to assess quantitatively the benefits and costs of the proposed rule and its alternatives. A complete regulatory analysis includes a discussion of non-quantified as well as quantified benefits and costs.

In theory, consumer surplus could be calculated by summing all of the use and passive-use benefits enumerated in Table 3 however in practice it is very difficult to quantify many of them. In some cases the methods exist, only resources are scarce to implement them. For example, we know that protected natural habitat, especially forest, provides important watershed functions. USDA Forest Service made an attempt to quantify the value of this watershed function in terms of clean water provided to downstream users by the 186 million acres of forest service lands (Sedell et al 2000). Their method generated a value estimate of $4.06 billion per year. Applying this same method to the 83.6 million acres in the park system could generate a significant, albeit smaller,[1] estimate. In the case of passive use values, estimates for NPS sites range from billions of dollars to "priceless," but more precise figures are not yet available. The only conclusive statement that can be made on the topic at this point in time is that it is an error not to acknowledge a positive value for passive-use.[2]

**Table 3:**
**Economic benefits of *RECREATION* AT NPS SITES**

| *NPS Sites* | *Visitors* | *Consumer Surplus* | *Social Benefit* |
|---|---|---|---|
| Historic/Memorial | 95,549,392 | $9.06 | $865,778,479 |
| Natural Resource-Based | 181,358,945 | $50.94 | $9,239,239,174 |
| All NPS Sites | 276,908,337 | -- | $10,105,017,652 |

Fortunately, a great deal of research has been conducted on the estimation of consumer surplus from recreation. The methods to determine consumer surplus from recreation include specialized surveys of visitors and using travel costs to trace out a demand curve for recreation at specific sites. A variety of U.S. Government departments and agencies use these methods such as the Department of Justice in assessing natural resource damage from oil spills, and the Environmental Protection Agency in estimating the benefits of regulations that protect natural ecosystems. A drawback of the methods for estimating consumer surplus from recreation is that they are data intensive and costly to implement. As a result, the U.S. Government allows estimates to be made based on extrapolations from existing studies (OMB Circular A-4).

NPS recently commissioned an updated summary of consumer surplus estimates relevant to national parks (Kaval and Loomis 2003) that included 1,239 estimates from 593 independent studies conducted at NPS sites and other wilderness areas in the U.S. The database includes estimates for a wide range of activities including hiking, backpacking, camping, bird watching and wildlife viewing, bicycling, fishing, and a host of others. The average consumer surplus from a single recreational visit to an NPS site was $50.94,[3] adjusted for inflation.[4] That is, an average park visitor enjoys approximately $51 of value beyond all the costs he or she incurs to visit a park.

The NPS study does not include estimates of consumer surplus from visits to historic sites, and indeed very little research has been conducted in this area. Only one peer-reviewed academic paper (Leggett et al 2003) examines a historic site in NPS, and provides an average consumer surplus value of $9.06, adjusted for inflation. Some reasons why this value is so low compared to natural resource-based parks is its location in an urban area where there are many substitute recreational activities, and the limited time spent by visitors at the site. Since there is only one study, we use this value only to illustrate our point – further study is required to develop and refine consumer surplus estimates for historic sites.

Given individual surplus values, we can compute the social economic benefit from recreation at NPS sites – that is, the total of all visitors' surplus values – by simply multiplying by the number of visitors. In 2004, the national park system received 276,908,337 visitors, and of them 35 percent visited historic sites. The economic benefit of recreational park visitation in 2004 was therefore $10.1 billion (see Table 3).

It is important to note that these estimates are subject to error generated by extrapolating from existing studies. Using an average value for park visits masks a great deal of the variation in the quality of experience across parks with very different attributes. In addition, the number of studies examining each activity conducted in parks varies and the

[1] It is important to note NPS lands are not only smaller in extension than USDA Forest Service, they also include vast areas of non-forested lands, as well as extensive areas in Alaska where there are few or no (human) downstream water users. Given that, the value estimate would likely not exceed $1 billion.

[2] While we are not able to include a precise passive use estimate, the Federal Government does support its consideration in administrative and judicial decision making (see Arrow, K., R. Solow, P.Portney, E. Leamer, R. Radner and H. Schuman. 1993. Report of the NOAA Panel on Contingent Valuation. Federal Register 58(10):4602-4614)

[3] Kaval and Loomis provide an average recreational surplus estimate of $52.08 from studies conducted solely at NPS sites. We chose to include a larger sample of studies (n=947 vs. n=49 for just NPS sites) that includes comparable wilderness areas and activities that occur at NPS sites, which provides an average value of $50.94. While a more conservative estimate, it is more robust given the larger sample size.

[4] All dollar figures adjusted for inflation through 2004 per CPI, Economic Report to the President.

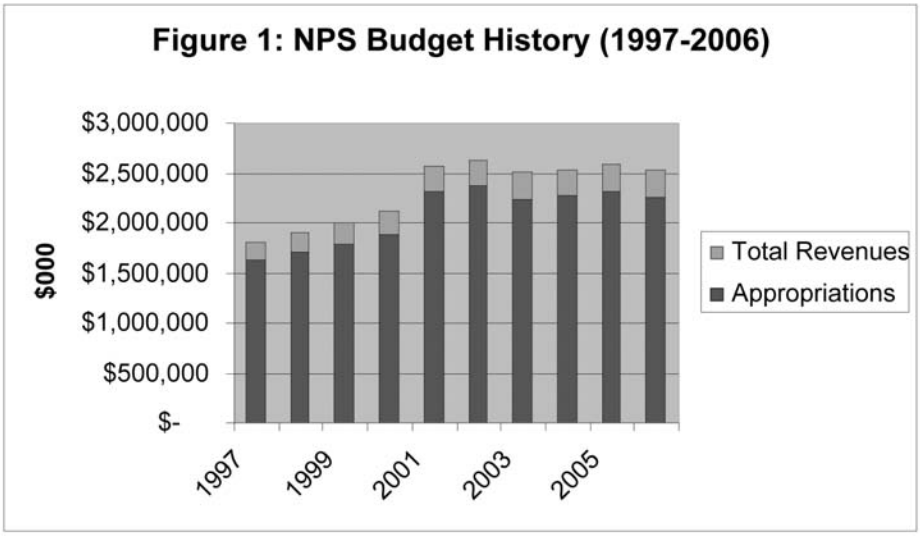
statistical variation in their results can be large. Also, the average value is based on a composition of studies on specific activities that may not represent the array of activities available at all parks. Lastly, for historic recreation, far more primary field research must be conducted at additional sites, many of which are materially different from Fort Sumter from which we derive the value in Table 3. We are able to resolve several of these issues in our treatment of case studies later in this chapter.

It is important to re-iterate that this estimate of $10.1 billion is conservative. One consideration is the rate at which consumer surplus for recreational visits to parks may increase over time. Since NPS sites are limited in area and access to wilderness areas continues to diminish, but population continues to increase, the value of a visit to an NPS site is likely to increase reflecting diminishing supply relative to demand. We must also restate that the benefits of the national park system extend well beyond that of recreation. If all use and passive-use values presented in Table 2 were quantified, the total social economic benefits of the national park system would likely be multiples of the recreational value of $10.1 billion. Passive use value for example of the Statue of Liberty, Mount Rushmore, Old Faithful, the Grand Canyon, Yosemite Valley, and many other sites in the system are likely to be priceless. Add to this ecosystem services and the intrinsic values of biodiversity protected at NPS sites and $10.1 billion may begin to seem a quite modest number.

**Costs of National Park Service**

The cost of NPS is simply the money spent in a given year to manage the system.[5] According to US Department of the Interior's Budget Justification for NPS, also known as the "Greenbook," federal appropriations in 2004, 2005, and 2006 were $2.3 billion, and were complemented by $0.3 billion in revenues, for a total budget of $2.6 billion (Figure 1).

In 1998, NPS with the assistance of National Parks Conservation Association, and more recently the Student Conservation Association, began a series of rigorous financial analyses of its sites called the Business Plan Initiative (BPI). These business plans provide an understanding of the current use of funding as well as the required budget to achieve a minimum standard of management.




Management functions include maintaining infrastructure, accommodating visitation, conservation for future generations, as well as research and study of the sites to improve management over time. According to recent calculations based on NPS business plans, the park system requires additional funding of $0.8 billion per year to achieve a basic level of management (this calculation focuses on the additional funds required for park operations and makes no allowance for additional investment in operating funds for regional or national NPS offices). That is, in order to continue providing the economic benefits of the parks in terms of current visitor satisfaction today and prevention of deterioration of the parks over the long term, the NPS budget must increase to about $3.4 billion per year.

**Cost-Benefit Comparison**

According to public finance theory, when the social economic benefits generated by a government project or program exceed the costs to implement it, there is a clear justification for government spending (Rosen 1988). The relationship between benefits and costs is often expressed as a ratio: such as, "the benefit-cost ratio of the project is 1.5," meaning the benefits to society are one and a half times the cost of the project – a favorable result. Some economists prefer to merely subtract costs from benefits to determine if the *net* social benefit is positive, again a signal for government to invest.

In the case of the national park system, we estimate the benefit-cost ratio by dividing annual social economic benefits, estimated to be greater than $10.1 billion by the annual NPS budget of $2.6 billion. The benefit-cost ratio is therefore greater than 3.9, and the net social benefit is greater than $7.5 billion – an admirable result for any public sector investment (Table 4). Considering only the estimable benefits presented here, NPS is generating economic benefits well in excess of the cost of maintaining the system. *In fact, the public enjoys at least*

[5]OMB recommends consideration of opportunity cost, which in this case is the commercial value of exploiting natural resources at NPS sites. Because this analysis does not consider changing the protected status of NPS sites, but only improved management, we do not estimate that opportunity cost here.

| TABLE 4: COST-BENEFIT RATIO OF NPS | | | |
|---|---|---|---|
| *NPS Economic Benefits* | *NPS Budget* | *Cost-Benefit Ratio* | *Justified Public Expenditure (Benefits/Cost > 1)?* |
| >$10.1 Billion | $2.6 Billion | >3.9 | YES |

**TABLE 5: ECONOMIC SURPLUS FROM RECREATION AT NPS CASE STUDY SITES**

| *NPS Sites* | *Visitation*[1] | *Recreational Value per Activity Day*[2] | *Recreational Benefits*[3] *($mil)* | *Budget*[4] *($mil)* | *Benefit to Cost Ratio* |
|---|---|---|---|---|---|
| **Acadia** | 2,207,847 | $45.47 | $100.4 | $7.1 | 14.1 |
| **Apostle Islands** | 151,881[5] | $45.08 | $6.8 | $2.6 | 2.6 |
| **Biscayne** | 478,304 | $39.83 | $19.1 | $3.4 | 5.5 |
| **Denali** | 404,236 | $49.49 | $20.0 | $14.1 | 1.4 |
| **Fort Sumter** | 781,239 | $9.06 | $7.1 | $1.8 | 4.0 |
| **Gettysburg** | 1,724,420 | $9.06 | $15.6 | $7.0 | 2.2 |
| **Joshua Tree** | 1,243,659 | $38.49 | $47.9 | $6.4 | 7.5 |
| **Point Reyes** | 1,960,055 | $62.05 | $121.6 | $8.6 | 14.1 |
| **Rocky Mountain** | 2,781,899 | $47.65 | $132.6 | $15.8 | 8.4 |
| **Sequoia & Kings Canyon** | 1,525,212 | $38.43 | $58.6 | $23.1 | 2.5 |
| **Shenandoah** | 1,261,000 | $55.48 | $70.0 | $15.7 | 4.4 |
| **Zion** | 2,677,342 | $36.82 | $98.6 | $9.4 | 10.5 |

[1] Visitation indicates number of visits to NPS site. Source: National Park Service Statistical Abstract 2004.
[2] Estimates of recreational value are based on NPS visitor studies indicating most common recreational activities and corresponding values for these activities drawn from a database of 947 recreational estimates per activity day (Kaval and Loomis 2003). For historic sites (Fort Sumter and Gettysburg), a consumer surplus estimate developed for Fort Sumter by Leggett et al (2003) is applied to both sites.
[3] Economic benefit estimates only reflect recreational values. A range of other potential site values (e.g., ecosystem services, science/education, passive use) are not reflected here (see Table 3). Therefore, these estimates should be viewed as conservative.
[4] In order to capture total funding (i.e., base funding plus other funding), we have drawn budget information from each park's most recent business plan. Where budget information is from fiscal years other than FY2004, it has been adjusted for inflation to 2004 dollars. No business plans were available for Biscayne and Fort Sumter; budget estimates for these sites reflect their base funding in FY2004.
Note: All figures adjusted to 2004 dollars.
[5] Visitation number believed to be an underestimate due to multiple unmonitored entry points to site.

*four times the value of each dollar spent by the federal government.*

We perform the same analysis for each of our twelve NPS case study sites (Table 5). The sites with the highest benefit to cost ratio are Acadia, Point Reyes, and Zion. The sites with the lowest ratios are Denali, Gettysburg, Sequoia & Kings Canyon, and Apostle Islands. Low ratios are the result of the remoteness and low visitation of Denali and Apostle Islands, and the potentially conservative surplus estimate for historic sites applied to Gettysburg. Nonetheless, all the case study sites show a benefit to cost ratio in excess of 1.

### Cost-Benefit Analysis of the NPS Budget Shortfall

What about the budgetary shortfall for NPS – how do we determine if additional funding should be allocated to the system? According to OMB, this assessment should include three elements: 1) a statement of the need for the proposed action; (2) an examination of alternative approaches; and, 3) an evaluation of the benefits and costs – quantitative and qualitative – of the proposed action and the main alternatives identified by the analysis.

*Statement of Need for the Proposed Action*

The *National Park System Organic Act* mandates that the National Park Service conserve, in an unimpaired state, the natural and historic amenities of the park system for present and future generations. But according to NPS business plans, the current NPS budget falls short of allowing the system to fully achieve this purpose. A recent study by the U.S. Government Accountability Office (2006) draws similar conclusions, noting that funding for daily operations has declined in inflation-adjusted terms from 2001-2005. As a result, parks are cutting services:

> *"All park units we visited received project-related allocations but most park units experienced declines in inflation-adjusted terms in their allocations for daily operations. Each of the 12 park units reported their daily operations allocations were not sufficient to address increases in operating costs, such as salaries and new Park Service requirements. In response, officials reported that they either eliminated or reduced services, or relied on other authorized sources to pay operating expenses that have historically been paid with allocations for daily operations" (US GAO 2006).*

Evidence of a decline in management is documented in a series of reports by National Parks Conservation Association (NPCA), entitled *State of the Parks and Faded Glory: Top Ten Reasons to Reinvest in America's National Park Heritage* (www.npca.org). According to NPCA, some of the main issues threatening NPS' ability to fulfill its purpose include:

- *Law enforcement* – NPS suffers from inadequate resources for law enforcement. In one park alone, Sequoia and Kings Canyon, park officials seized $176 million worth of marijuana plants in 2004. In 2002, NPS recorded 11,000 violations of the Archaeological Resources Protection Act of 1979. In its fiscal 2005 budget, NPS identified illegal removal of wildlife as a factor in the decline of at least 29 species of wildlife, and could cause extirpation of 19 species from parks. Illegal fishing and coral poaching are causing degradation of Virgin Islands National Park and Biscayne National Park. In addition, NPS needs resources

to meet demands of Homeland Security requirements.

- *Invasive species* – Approximately 2.6 million acres of parkland host non-native invasive species, changing the structure and function of the ecosystems NPS is charged to conserve. Plants, fish, and insects from as far away as South America and Asia are replacing native species in many parks. For example, in Theodore Roosevelt National Park in North Dakota, more than 60 non-native species have found their way into the park – including leafy spurge that invades native grasslands that wild bison and elk depend on for food. Joshua Tree National Park is overrun by non-native grasses such as cheatgrass and red brome, which spur wildfire and compete with native species for water.

- *Historic preservation* – Inadequate resources have resulted in insufficient care and preservation of historic artifacts, buildings, and other structures. More than half of the 100 million items in NPS collections have yet to be catalogued or shared with visitors. Two thirds of historic buildings and structures in the national parks are in need of repair.

- *Infrastructure* – Backlogged road and bridge repair at NPS sites exceeds $3 billion. In addition, damages caused by natural events such as hurricanes add a significant burden to repair budgets.

To some extent, NPS attempts to measure its effectiveness through periodic visitor surveys. The survey asks visitors to rate their experience at various NPS sites based on measures such as the quality of facilities, educational resources and ranger accessibility. However, solid marks on the visitor survey do not tell the entire story. Many of the issues identified above are not covered in the survey nor can many of these issues be immediately detected during a typical recreational visit.

*Examination of Alternative Approaches*

Cost-benefit analysis generally tests the difference between one or more alternatives. Often, the test is between the current situation ("baseline") and a proposed change. In this case we evaluate two alternatives: a) leave the budget unaltered; or b) allocate an additional $800 million to NPS in annual funding.

We must also look at the issue from one of two perspectives. Some contend that NPS sites are in a state of decline and that the proposed increase in budget is required to maintain basic operations. Others may contend that the national park system is maintained in suitable condition and any increase in budget would only be justified by marked improvement in NPS sites. We examine both positions.

*Evaluation of Benefits and Costs*

We assess the merits of the two alternatives by comparing the costs and benefits of the proposed change in the NPS budget, allowing us to determine which of the two alternatives produces the greater economic return to society. The cost implications of the two alternatives are clear. In the first scenario, costs remain as currently budgeted at $2.6 billion per year. In the second scenario, costs rise by $800 million per year, to a total annual budget for NPS of approximately $3.4 billion. The benefits are more difficult to quantify. Given the available data, it is not possible to estimate accurately the difference in benefits between the two scenarios.

However, we can perform a threshold analysis that tells us the degree of change in the quality of NPS sites that would justify an increase in spending, keeping in mind that such an increase may either just prevent further degradation of NPS sites or might improve them. In the simplest[6] form of this analysis we consider the NPS budget shortfall ($800 million) as a percentage of national park system-wide economic benefits (>$10 billion) – a threshold figure of about eight percent. This suggests funding the NPS budget shortfall is justified where it would increase park benefits, or prevent the loss of park benefits, by eight percent.

The next question is: how likely is it that funding the budget shortfall would generate an eight percent change in economic benefits (increase, or prevention of loss)? One way of answering that question is to examine recreational benefits, where the potential change in *quantity* of park visitors or the *quality* of the visitor experience, both of which are factors in the total economic value of recreation at national parks. Because it is easiest to measure changes in park visitation, we will use only that variable for this example, but it is important to note that changes in visitor experience are equally as important in generating economic benefits estimates (e.g. an increase in the quality of a visitor's experience may increase total economic value by as much or more than additional visitation). So, examining only changes in visitation, we assume a change in park quality would affect visitation over time, and we ask whether an eight percent change in visitation (which translates into an eight percent change in recreational benefits, all other things being equal) seems likely relative to normal variability of park visitation. Over the past ten years the difference between the lowest visitation year and highest was eight percent (U.S. Department of Interior 2006). In this context, our conclusion is that indeed, an overall change in economic benefits of eight percent due

[6]This analysis does not account for inter-temporal effects of budgetary changes. Impacts such as invasive species may not be perceived immediately, but may have costly long-term impacts. A more sophisticated modeling approach is necessary to fully account for the temporal nature of such impacts, and to calculate net present value of future costs and benefits accordingly.

**TABLE 6:**
**ANALYSIS OF ESTIMATED BUDGET SHORTFALLS AND THRESHOLD ANALYSIS FOR NPS SITES**

| *NPS Sites* | *Economic Benefits -- Recreation ($mil)* | *Budget ($mil)* | *Estimated Total Budget Needs[1] ($mil)* | *Budget Shortfall ($mil)* | *% Funding Increase Required to Meet Budget Needs* | *Budget Shortfall as % of Economic Benefits* |
|---|---|---|---|---|---|---|
| **Acadia** | $100.4 | $7.1 | $15.1 | $8.0 | 112% | 8.0% |
| **Apostle Islands** | $6.8 | $2.6 | $6.4 | $3.7 | 141% | 54.4% |
| **Biscayne** | $19.1 | $3.4 | $4.2 | $0.8 | 22% | 3.9% |
| **Denali** | $20.0 | $14.1 | $18.0 | $3.9 | 28% | 19.6% |
| **Fort Sumter** | $7.1 | $1.8 | NA | NA | NA | NA |
| **Gettysburg** | $15.6 | $7.0 | $10.8 | $3.8 | 54% | 24.3% |
| **Joshua Tree** | $47.9 | $6.4 | $9.2 | $2.8 | 44% | 5.9% |
| **Point Reyes** | $121.6 | $8.6 | $13.9 | $5.2 | 61% | 4.3% |
| **Rocky Mountain** | $132.6 | $15.8 | $19.3 | $3.5 | 22% | 2.7% |
| **Sequoia & Kings Canyon** | $58.6 | $23.1 | $38.0 | $14.8 | 64% | 25.3% |
| **Shenandoah** | $70.0 | $15.7 | $23.8 | $8.0 | 51% | 11.5% |
| **Zion** | $98.6 | $9.4 | $14.3 | $4.8 | 52% | 4.9% |

[1] Estimates of total budget needs are based on each site's business plan. Where business plans are not from 2004, budget needs are adjusted for inflation to 2004 dollars. No business plans were available for Biscayne and Fort Sumter; estimates of budget needs for Biscayne are based on National Parks Conservation Association, State of the Parks: Biscayne National Park 2006. No estimates of budget needs are available for Fort Sumter.
Note: All figures adjusted to 2004 dollars.

to changes in visitation alone is well within the realm of possibility. Now, considering that an improvement in the quality of the visitor experience also increases recreational benefits, you may conclude that *less* than an eight percent increase in visitation could generate sufficient economic benefits to justify the proposed increase in park budgets.

From this analysis it is readily seen that the threshold is quite low for justifying the proposed budget increase for NPS in terms of just recreational benefits. It is important to mention that a number of economic benefits enumerated earlier in this section have not been quantified in this analysis – most of which do not rely on increased visitation. If we had included those benefits in the threshold analysis, the results would be even more convincing. In other words, the proposed budget increase is an economically justifiable public policy decision.

We performed a similar analysis for our 12 case study sites to illustrate the application of this methodology at a site level (Table 6). As expected the threshold to justify proposed budget increases varies, falling both above and below the national figure of eight percent. NPS sites with lower thresholds are Rocky Mountain, Biscayne, Point Reyes, Zion, and Joshua Tree. The most remote and least visited, Apostle Islands, has the highest threshold necessary to justify proposed budgetary increases. Again, we re-iterate that we estimate economic benefits for recreation alone, which is a function of visitation and quality of the visitor experience. Because remote parks such as Apostle Islands have low visitation, their recreational benefits are commensurately low, but the other non-quantified benefits (e.g. passive use) may still be great.

## Conclusion

Despite limitations to quantifying economic benefits of the national park system, available data are sufficient to demonstrate clearly the justification for funding NPS. More important, failure to address budget shortfalls by fully funding needs delineated in NPS site-level business plans may cause a decline in economic benefits generated by parks. Such a decline, involving the deterioration of natural and man-made assets of the system, could result in long-term economic losses to society far in excess of the short-term budgetary savings from failing to fully fund the NPS budget.

This analysis is carried by quantitative estimates for consumer surplus from recreation at NPS sites. This however is only the beginning of the economic value generated by NPS sites – most values have yet to be quantified. Once considered, the full range of use and passive-use values would make an already decisive analysis even more convincing.

# Chapter 3: Economic Impacts of National Parks

**TABLE 7: NPS SYSTEM-WIDE LOCAL ECONOMIC IMPACT ESTIMATES**

| *Annual visitor spending ($billion)* | *Sales ($billion)* | *Personal income ($billion)* | *Jobs* | *Value Added ($billion)* |
|---|---|---|---|---|
| 11.3* | 13.3 | 4.8 | 267,000 | 7.5 |

* Public sector (NPS) spending adds $2-3 billion to this estimate for a total of about $14 billion in annual direct spending.
Source: Stynes and Sun 2003
Note: All figures adjusted to 2004 dollars.

Economic impact analysis is an approach used by policymakers, industry, and others to assess how flows of economic activity affect local output, employment, and income. Such flows may range from tourism spending to the opening of a new manufacturing plant. Unlike cost-benefit analysis (Chapter 2), which estimates net *benefits to society,* economic impact analysis measures *economic activity* for specific regions or economic sectors.

National parks and surrounding communities have a shared interest in understanding the economic impacts of parks on the local economy. In response to these needs, the National Park Service (NPS) developed the *Money Generation Model* (MGM) in 1990 to estimate park visitor spending in the local area and the impacts of this spending on a number of economic indicators, including sales, personal income, jobs, and value added.[7] The model was updated in 2000 as MGM2, with estimates developed for the overall national park system, as well as specific parks (Stynes and Sun 2003). New and updated estimates continue to be made available at http://web4.canr.msu.edu/MGM2/.

In simplified form, MGM2 estimates economic impacts by multiplying the number of park visitors by average spending per visitor and regional economic multipliers. The initial impact of visitor spending (e.g., park, restaurant, lodging, and retail spending) are the "direct effects." Then multipliers capture the "secondary effects" of visitor spending as it re-circulates through the local economy.[8] The MGM2 approach involves segmenting visitors by local residents, non-local visitors on day trips, and overnight visitors (motel or camping), and applying different spending estimates to each segment. Key visitor spending categories omitted from the MGM2 model include airfares and transportation expenses outside the local region, as well as durable goods purchases and other at-home expenses. Impacts of park operations and construction activity are estimated in a separate model (Stynes, personal communication, 4/13/06).

**Economic Impact Estimates: System-Wide and Case Study Sites**

According to MGM2 estimates, national park visitors spent $11.3 billion in areas local to parks in 2004.[9] The direct effects of this spending supported $9.2 billion in sales and 212,000 jobs at local tourism-related businesses, generated $3.3 billion in personal income, and provided $4.9 billion in value added.[10] When multiplier effects are taken into account, the total economic impact of visitor spending in areas surrounding parks was $13.3 billion in sales, 267,000 jobs, $4.8 billion in personal income, and $7.5 billion in value added (Table 7). However, as noted by Stynes and Sun (2003), these represent conservative estimates due to the assumptions of the MGM2 model. They speculate that "estimates counting all visitor spending would be 2-4 times greater than the figures reported here."

Moreover, it should be noted that MGM2 spending estimates for local park regions do not reflect public sector spending by NPS on operations, projects, and so forth. System-wide, this would add approximately $2-3 billion to direct spending estimates – for a total of about $14 billion (Stynes, personal communication, 1/10/06).

In addition to system-wide estimates, we examine economic impacts for our 12 NPS case study sites. Table 8 presents estimates for each park produced by the MGM2 model in 2003 (adjusted to 2004 dollars). The sites with the highest total visitor spending are Rocky Mountain and Acadia, reflecting their high visitation levels and park

[7]"Sales" (or output) is the dollar value of goods or services produced or sold. "Personal income" includes wages, salaries, and payroll benefits. "Jobs" reflects the number of jobs required to produce a given volume of sales/production. "Value added" represents the contribution to gross regional/local product. It includes personal income, profits and rents of private firms, and indirect business taxes accruing to regional/local government.

[8]Capturing secondary effects generally requires the use of input-output models. MGM2 relies on IMPLAN, a software and database package for estimating 528 sector-specific input-output models for any region consisting of one or more counties.

[9]Economic impacts reflect the most recent MGM2 estimates for national park system-wide local economic impacts (2001), adjusted for inflation to 2004 dollars.

[10]The difference between visitor spending ($11.3 billion) and direct sales ($9.2 billion) of $2 billion occurs because this spending is for goods and services provided outside of the local economy.

area spending opportunities. In the local areas of the two parks, this spending supports about $400 million in sales, close to 9,000 jobs, and more than $200 million in value added. While Zion receives a similar number of visitors as Rocky Mountain and Acadia, total visitor spending for Zion is only about half as much as these parks due to more limited spending opportunities in Zion's local area. Visitor spending was lowest for Apostle Islands. Due to the park's remote location, it receives fewer visitors and spending opportunities in the surrounding area are limited.

**Opportunities for Refining and Extending Impact Estimates**

Developing a model for estimating the economic impacts of each park and historic site within the national park system is no easy task. System-wide, there are a great diversity of sites and visitors, but limited data on visitation patterns and spending. In addressing such problems, MGM2 sets forth a range of modeling parameters and assumptions as a basis for estimating park-specific and system-wide economic impacts. The model incorporates park-specific visitor survey data where available, and where it is not, favors conservative assumptions as a means of ensuring estimates (at least as a lower bound) are defensible.

With system-wide visitor spending around parks of about $11 billion, generating $13.3 billion in sales and supporting 267,000 jobs, the MGM2 model provides clear evidence that the local economic impacts of national parks are substantial. While we support the MGM2 model's approach to estimation, our analysis of case study sites suggests there may be opportunities for refinements that could contribute to improved park-specific estimates, as well as a better understanding of park economic impacts beyond local areas. Below we explore these opportunities, highlighting factors for consideration.

***Incorporating park-specific information to improve visitor spending estimates.*** Each national park is unique, but general spending averages embedded in the MGM2 model do not capture spending variations associated with these unique characteristics. As visitor surveys are conducted, these characteristics can better be taken into account in spending profiles. But presently, visitor survey information is only available for a small number of parks. For other parks MGM2 applies an assumption of "high," "medium," or "low" spending based on an evaluation of spending opportunities and other factors (e.g., local retail activity). However, even without visitor survey data, there may be park-specific information available that, if taken into account, could contribute to improvements in the precision of spending estimates. For example:

- *Fort Sumter National Monument* – According to MGM2, Fort Sumter received 840,000 visits in 2003 and overall visitor spending was $17.3 million, or about $20 per visitor. However, accounting for visitor spending on the ferry ride to Fort Sumter alone would add about 50 percent to this total. The ferry charges $12 for adults, $11 for seniors, and $6 for children ages 6-11, so a rough average of $10 per visitor would equal about $8.4 million in visitor spending.

- *Denali National Park and Preserve* – Numerous businesses provide services within the park, from lodging and food, to supporting hiking, mountaineering, and rafting trips, to providing air taxi and flightseeing services. Denali's contracts with these businesses provide a source of information on visitor spending, as nearly all gross receipts of these businesses reflect visitor spending. In 2002, gross receipts of these businesses were over $15 million, with the major park concession to ARAMARK for lodging, campgrounds, food, and tours accounting for about 75 percent of the total.

***Adjusting the definition of "local" area, where appropriate.*** MGM2 estimates only capture a subset of visitor spending, within 50-100 miles of national parks. This approach is taken to ensure spending can be attributed to the park visited. For some parks, gateway communities are located outside the 50-100 mile radius applied by MGM2. Where challenges of attribution can be surmounted, adjustments to account for spending in these gateway areas would improve impact estimates. For example:

**TABLE 8: LOCAL ECONOMIC IMPACT ESTIMATES FOR NPS CASE STUDY SITES**

| *NPS Sites* | *Total annual visitor spending ($mil)* | *Sales ($mil)* | *Personal income ($mil)* | *Jobs* | *Value Added ($mil)* |
|---|---|---|---|---|---|
| **Acadia** | $137.1 | $172.8 | $61.7 | 3,556 | $97.0 |
| **Apostle Islands** | $7.5 | $7.9 | $2.7 | 195 | $4.3 |
| **Biscayne** | $24.0 | $28.9 | $11.3 | 425 | $17.7 |
| **Denali**[1] | $22.7 | $27.1 | $9.7 | 562 | $15.4 |
| **Fort Sumter** | $17.8 | $20.0 | $7.6 | 391 | $12.0 |
| **Gettysburg** | $95.2 | $112.3 | $37.5 | 2,851 | $59.7 |
| **Joshua Tree** | $49.3 | $62.3 | $23.2 | 1,152 | $36.6 |
| **Point Reyes** | $89.0 | $111.0 | $41.5 | 2,065 | $65.4 |
| **Rocky Mountain** | $193.6 | $209.3 | $71.1 | 5,178 | $112.6 |
| **Sequoia & Kings Canyon** | $73.9 | $102.2 | $39.5 | 1,882 | $61.3 |
| **Shenandoah** | $43.9 | $55.1 | $20.5 | 1,010 | $32.3 |
| **Zion** | $83.1 | $95.4 | $34.7 | 2,013 | $54.7 |

[1] MGM2 spending profiles do not apply well to Denali or other Alaskan parks. Spending averages are based on surveys of visitors to parks in the lower 48 states; they do not reflect a range of spending common for visitors to Alaskan parks. The MGM2 definition of region (50-100 miles from the park) and visitor segments also do not apply well (Stynes, personal communication, 4/13/06).
Source: National Park Service Money Generation Model 2, see http://web4.canr.msu.edu/MGM2/
Note: All figures adjusted to 2004 dollars.

- *Denali National Park and Preserve* – Nearly all visitors to Denali travel through Anchorage, either arriving there by air or via a cruise ship. On their way to Denali, these visitors may spend money on lodging in Anchorage, as well as food, retail, and transportation. While the MGM2 model captures visitor spending within Denali's small gateway community of Glitter Gulch, a great proportion of visitor spending occurs outside this community, in Anchorage and on travel to and from the park. For illustration, Alaska visitor expenditure studies indicate that the average vacation/pleasure visitor spent $119/night in 2001 (Northern Economics 2002). If one additional night of visitor spending were attributed to Denali visitors (e.g., spending in Anchorage or elsewhere outside the park and Glitter Gulch), this would add about $50 million to park visitor spending. Consider that MGM2 estimates visitors to Denali spent only $22 million in 2003, and it is clear that assumptions about the inclusion and attribution of visitor spending can substantially affect overall spending and impact estimates.

***Estimating impacts at the state level, where appropriate.*** Where park impacts are substantial and extend well beyond local areas, conducting an additional impact analysis at the state level may provide a more complete picture of a park's economic impacts. For example:

- *Acadia National Park* – Nearly all visitors to Acadia travel there by car (Littlejohn 1999), following a travel corridor of more than 200 miles through the state of Maine. Traveling to and from the park, many of these visitors spend money shopping at retail outlets, and for food and lodging. Acadia is the primary destination of many of Maine's tourists. A recent study of travel and tourism found that 21 percent of overnight visitors to Maine in 2004 visited Acadia/Bar Harbor, and 18 percent of overnight visitors indicated that visiting the Acadia/Downeast region was their primary reason for travel to Maine (Longwoods International 2005).

***Estimating economic impacts of international visitors to national parks.*** Little is known about the role national parks play in attracting international visitors to the United States. For example, a recent visitor study of Joshua Tree National Park (Le et al 2004) indicates international visitors comprised eight percent of total visitation, equal to about 100,000 international visitors. About 30 percent of visitors were from Canada, 40 percent from England and Germany, and the remainder from 15 other countries. A study might aim to estimate the number of international visitors at each park, the importance of national parks in generating trips to the U.S., and the spending of these visitors.

**Conclusion**

Conservatively estimated, visitors to national parks spend over $11 billion annually in the local regions of the parks, supporting $13.3 billion in sales, 267,000 jobs, and 7.5 billion in value added. If all visitor spending were taken into account (e.g., spending outside the local area), estimates might be 2-4 times greater. Clearly, national parks play an important role in the economies of their surrounding communities, as well as in the national tourism economy.

In considering the economic significance of national parks, however, caution should be taken in lending too much weight to local economic impacts. As noted by Stynes and Sun (2003), much of the value parks provide society is not reflected in economic impacts:

> *"The values that most people associate with National Parks are very different from those captured in an economic impact analysis. From an economic impact standpoint, the most valuable park visitors are likely 'windshield tourists', who make a quick tour of the park and head for souvenir shops, restaurants and other commercial attractions, usually in the gateway communities outside the park. Park visitors do not spend money while in the backcountry or engaged in activities such as hiking, fishing, observing nature, or learning about history within the park."*

Impacts represent an important measure of the role of national parks in local economies. But to develop a more complete picture of parks' economic significance, a broader set of indicators needs to be considered that includes economic benefits, impacts, and growth.

# Chapter 4: Economic Growth and National Parks

Another aspect of the economic importance of the national park system is its role in local economic growth. Since the creation of the country's first national park, Yellowstone in 1872, communities have debated over the potential economic impact of parks. Debate most often focused on the conservation of natural resources that might otherwise be used for economic purposes, such as timber and minerals, as well restrictions on the development of tourism facilities in areas of public interest slated to become protected. Contemporary analysis of economic growth patterns around parks and other wilderness areas in the U.S. suggest that protected lands actually correlate more with greater economic growth than do lands utilized for natural resource exploitation. Indeed, some analysts today view NPS sites as engines for rural economic development, especially in an era of rapidly improving telecommunications and transportation infrastructure that allows professionals to locate close to the natural amenities that national parks provide. Today, debate is shifting from *whether* growth will happen, to how to manage it. NPS and neighboring communities may need to work together to ensure that the increasing jobs, income, and population do not threaten the natural amenities that serve as the engine of this growth.

### Measuring Economic Growth

Economists measure growth of an economy in a variety of ways. Many people are familiar with the term *Gross Domestic Product* (GDP), for example, which measures the total activity in an economy. Other measures include changes in population, jobs, per capita income, and earnings per job, among others. All of these measures tell us how the economy, in aggregate, is doing. Further examination of growth also includes measuring the distribution of wealth and affordability of basic necessities, such as housing, to discern how economic circumstances are changing for different segments of the population. It is necessary to look at this wide variety of measures to have a complete picture of economic growth.

### Amenity-Driven Economic Growth

In recent years geographers have turned their attention to the phenomenon of rapid growth rates in rural areas of the U.S. Most explain this as *amenity-driven growth*, where individuals choose to live near wilderness areas where quality of life is considered high due to outdoor recreation opportunities, small town characteristics, and scenic beauty. In a recent series of studies edited by Green et al (2005), geographers examine the importance of natural amenities versus other drivers of migration. They conclude that rural areas in the U.S. with protected lands and other natural amenities (wilderness areas) are growing faster than other rural areas, and since 1970 faster than metropolitan areas (Table 9), and that natural amenities are one important factor in determining growth, as are infrastructure and accessibility. USDA Forest Service (2004) published a review of approximately 80 studies of amenity-driven growth and arrived at much the same conclusions.

A facet of this analysis is referred to as "Old West" versus "New West," where amenity-driven growth in western U.S. states is compared to growth driven by natural resource exploitation, such as logging and mining. A common complaint of placing lands under protection is the consequent loss of jobs in these industries. However, multiple analyses indicate that there is no loss in economic growth in areas with protected lands, and in some cases growth exceeds that of similar nearby areas that rely on natural resource exploitation. In a 1998 study Duffy-Deno found there to be no difference in growth between counties in the eight states of the inter-mountain west that relied on logging and mining and those that had protected lands. In a 2000 study, Lorah found that counties with protected lands are developing new and more diverse economic activities that in fact counterbalance the economic decline of natural resource industries. Economic diversification also tends to be complemented by migration of retirees to areas rich in natural amenities (McGranahan, 1999). Lorah and Southwick (2003) go on to find that growth in areas adjacent to protected areas is faster than other rural areas throughout the western U.S. All of these findings are corroborated by further evidence from a series of empirical studies conducted by Sonoran Institute (2004).[11] As more studies are completed, the trend appears to show that natural resource industries are declining in the U.S. relative to the types of economic activity that occur in ameni-

**TABLE 9: Percent County Population Change**

| *Decade* | *Metropolitan* | *All Non-Metropolitan* | *[Proximate to] Wilderness* |
|---|---|---|---|
| *1960-1970* | 17.1% | 4.3% | 12.8% |
| *1970-1980* | 10.6% | 14.3% | 31.4% |
| *1980-1990* | 11.6% | 3.9% | 12.0% |
| *1990-2000* | 13.9% | 10.2% | 29.9% |

Source: Dearien et al 2005, as adapted from Rudzitis, 1996

ty-rich areas, which attract not only tourism but also retirees and knowledge-based businesses that need only good telecommunications and air travel infrastructure ("modem cowboys").

The eastern U.S. states have not enjoyed the same level of attention from researchers of this phenomenon. Some possible reasons are that the political debate over resource exploitation versus conservation has not been as dramatic, or that sprawling development patterns of the more urbanized east coast produce less focused examples of amenity-driven growth than the geography of western states permits. The latter point raises a broader question regarding how much large urban areas may be impacted by varying degrees of proximity to natural amenities. Schmidt and Courant (2005) examined 90 metropolitan areas in all regions of the U.S. and determined that those cities with relatively easier access to national parks, national seashores, and national lakefronts served to draw labor, as measured by a willingness to accept measurably lower compensation. This demonstrates that natural amenities may have a further reach in terms of economic growth than previous researchers identified.

While economies are growing and diversifying in rural areas rich in natural amenities, the benefits are not always shared equally across all social classes. Rasker (2004) documents three concerning patterns that have emerged. First, per-capita income is rising without a commensurate increase in earnings per job. This reflects the increasing number of in-migrants, especially retirees, who have high levels of investment income. Second, the polarization of wealth is increasing. This relates to the disparity between those that rely on earned vs. investment income as well as new migrants with higher compensation that work in knowledge-based industries. Third, with more wealth entering small rural economies, housing costs tend to rise. When housing costs rise and earned income does not keep pace, housing affordability falls. In those communities with a large tourism industry dependent on service workers, these stresses can become acute.

### Economic Growth and National Parks

Specific studies of economic growth around NPS sites follow the findings of the more generalized analyses of amenity-driven growth near wilderness areas. In this section we summarize several case studies found in the literature, and then present an analysis of economic growth data for our 12 case study NPS sites.

The greater Yellowstone area surrounding Yellowstone National Park and Grand Teton National Park has shown remarkable economic growth. A study performed by Rasker and Hansen (2000) documents the shift in the regional economy from extractive industries to service occupations, retirement, and investment income. Rasker and Alexander (2003) show that the area's population grew by 61 percent over the last thirty years (compared to 38 percent nationally). In large part, the establishment of new small companies has driven economic growth since 1990, some of which include high-wage professional services (engineering, finance, legal, insurance, real estate). Personal income growth in the greater Yellowstone area has outpaced state averages for Idaho, Montana, and Wyoming. Like many other areas with amenity-driven growth, however, non-labor income represents a significant portion of personal income and earnings among wage laborers have actually declined.

Flathead County, next to Glacier National Park, presents another story of strong economic growth. National Parks Conservation Association (2003) compiled three studies by researchers at University of Montana that present perspectives on growth in the county. The studies show that the economy of Flathead County is vibrant, diverse, and growing. All indicators studied (population, workforce, employment, personal income, total labor earnings, and wage & salary earning) all exceed growth rates for Montana, western U.S. states, and the nation.[12] Interviews with visitors, new residents, and lifelong residents of Flathead County indicate recognition that the main driver of growth is the natural environment and that Glacier National Park is the anchor for Flathead County's robust economy. There is also a recognition that the natural amenities of the region are at risk from economic growth and that the county must plan to manage the risks of growth to its natural amenities.

In an edited volume entitled *National Parks and Rural Development* (Machlis and Field, 2000), contributing author Miles provides a counter-balance to the growth story seen around many other national parks. The three national parks of the Pacific Northwest, Mt. Rainier National Park, Olympic National Park, and North Cascades National Park, have all shown remarkably little growth in neighboring communities. The study shows that three factors are at play: proximity to urban areas allowing for convenient day visits; high seasonality due to poor winter weather conditions; and development restrictions in surrounding areas. What the case study does not consider is the growth benefit enjoyed by Seattle, from which most day visits originate. Seattle is often cited as an example of a city with

[11]Responding to a burgeoning interest in economic growth adjacent to wilderness areas, the U.S. Bureau of Land Management partnered with the non-governmental organization, Sonoran Institute, to develop a database program that allows rapid assessment of growth patterns in the U.S. According to Sonoran Institute, the system is now widely used by additional government agencies such as U.S. Forest Service, National Park Service, as well as county planners.

[12]The study cites data from U.S. Bureau of Labor Statistics, U.S. Department of Commerce.

amenity-driven growth, and Schmidt and Courant (2005) show that proximity to national parks is a factor.

We examined economic growth patterns around our 12 NPS case study sites over the period 1970 through 2003 (Table 10). Population, employment (with the single exception of Shenandoah National Park), and personal income growth all outpaced the state in which the sites are located. On an annual average, these indices were one percent greater, which over a period of years compounds to very large differences in growth. However, earnings per job grew more slowly across the sites. We did not find a pattern of declining housing affordability, and more generally housing affordability followed trends similar to state-wide indices. In several cases we did not analyze growth patterns due to parks' close proximity to urban areas increasing the potential to confound park-led growth with other factors (Biscayne, Fort Sumter, Joshua Tree, and Point Reyes). In the case of Denali, economic data are not sufficient to perform the analysis.

**TABLE 10:**
**ECONOMIC GROWTH IN NPS SITE AREAS COMPARED TO STATE, 1970 TO 2003[1]**

| NPS Sites | Area: Local[2] vs. State | Annual Population Growth 1970-2003 (%) | Annual Employment Growth 1970-2003 (%) | Annual Personal Income Growth 1970-2003 (%) | Median Earnings per Job 2003 ($'000) | Housing Affordability: Index and Affordability Trend 1990-2000[3] 1990-2000 | Trend |
|---|---|---|---|---|---|---|---|
| **Acadia** | Local | 1.3 | 2.9 | 3.2 | 27.3 | 103 to 141 | More |
| | State | 0.8 | 1.8 | 2.6 | 33.5 | 110 to 162 | More |
| | Difference | 0.5 | 1.1 | 0.6 | -6.1 | | Same |
| **Apostle Islands** | Local | 0.8 | 2.1 | 2.6 | 19.3 | 163 to 163 | Same |
| | State | 0.6 | 1.7 | 2.1 | 37.6 | 167 to 167 | Same |
| | Difference | 0.2 | 0.4 | 0.5 | -18.3 | | Same |
| **Biscayne[4]** | NA | | | | | | |
| **Denali[5]** | NA | | | | | | |
| **Fort Sumter[4]** | NA | | | | | | |
| **Gettysburg** | Local | 1.6 | 2.2 | 2.9 | 27.9 | 128 to 157 | More |
| | State | 0.1 | 0.9 | 1.7 | 41.9 | 150 to 179 | More |
| | Difference | 1.5 | 1.3 | 1.2 | -14.0 | | Same |
| **Joshua Tree[6]** | NA | | | | | | |
| **Point Reyes[4]** | NA | | | | | | |
| **Rocky Mountain** | Local | 3.3 | 4.9 | 5.6 | 37.0 | 130 to 121 | Less |
| | State | 2.2 | 3.2 | 4.0 | 43.6 | 129 to 119 | Less |
| | Difference | 1.1 | 1.7 | 1.6 | -6.7 | | Same |
| **Sequoia & Kings Canyon** | Local | 2.2 | 2.6 | 3.0 | 34.9 | 107 to 132 | More |
| | State | 1.7 | 2.4 | 2.9 | 47.5 | 62 to 89 | More |
| | Difference | 0.5 | 0.2 | 0.1 | -12.6 | | Same |
| **Shenandoah** | Local | 1.9 | 2.1 | 3.6 | 25.5 | 131 to 151 | More |
| | State | 1.4 | 2.4 | 3.4 | 43.9 | 125 to 153 | More |
| | Difference | 0.5 | -0.3 | 0.2 | -18.3 | | Same |
| **Zion** | Local | 5.2 | 6.2 | 6.5 | 25.7 | 112 to 109 | Less |
| | State | 2.4 | 3.5 | 3.9 | 35.0 | 143 to 124 | Less |
| | Difference | 2.8 | 2.7 | 2.6 | -9.3 | | Same |
| **Total** | Local | 2.3 | 3.3 | 3.9 | 28.2 | 125 to 139 | More |
| | State | 1.3 | 2.3 | 2.9 | 40.4 | 127 to 142 | More |
| | Difference | 1.0 | 1.0 | 1.0 | -12.2 | | Same |

[1] All estimates calculated using the Bureau of Land Management and Sonoran Institute Economic Profile System 2003 version.
[2] A park's local area is defined as the county or counties surrounding the park or located at the gateway to the park.
[3] A housing affordability index estimate of 100 or above indicates that the median family can afford the median house. Higher estimates reflect greater affordability.
[4] Growth trends are not analyzed because the park's close proximity to an urban area creates a high potential for confounding park-led growth with other factors.
[5] Insufficient data for analysis. However, Denali amenity values are unlikely to be a major factor in growth trends due to the effect of other factors (e.g., climate, remoteness/proximity to markets). And any local growth would be small in absolute terms, as the population of Denali borough is less than 2,000.
[6] Joshua Tree is located in the largest county (San Bernardino) in the contiguous United States. A county-level growth analysis would have high potential for confounding park-led growth with other factors.

## Smart Growth

Growth is a "double-edged sword" in that it generates jobs and income but it also can create stress on the natural amenities in a region. Development sprawl is a major issue near those NPS sites where growth is most aggressive. The phenomenon of growth near parks has received national attention, as exemplified by USA Today running an article entitled "Developers covet areas surrounding national parks" on March 21, 2006. Sprawl can result in a reduction in important wildlife habitat (and subsequent human-wildlife conflicts), environmental pollution, congestion and loss of the natural aesthetic of a wilderness area. It is possible to relegate these impacts as necessary costs of economic growth, but it is important to recognize the magnitude of that cost and to determine whether new jobs and income justify it.

In cases where growth threatens the natural amenities of NPS sites, there is a cost incurred by society. That cost can be readily quantified in terms of diminished visitor experience and a subsequent reduction in visitation. As we describe in other chapters of this report, the national-level economic benefits in terms of consumer surplus for recreation generated by NPS sites is at least $10.1 billion per year. Add to this the other sources of consumer surplus generated by parks and the number may increase by multiples. We also describe in this report the economic impact of tourist spending at NPS sites. Total annual spending is in the range of $11 billion, generating added value (wages, rents, and business profits) of $7.5 billion. The source of these benefits lays in the physical condition of NPS sites – the natural amenities that attract visitors. Congestion, pollution, ecological deterioration, diminished wildlife viewing or human-wildlife conflicts all may cause a deterioration of the benefits accruing to visitors (as well as non-visitors).

It is important to emphasize two policy implications of threats posed by rapid growth near national parks. First, to the extent that policy makers justify government spending on NPS in strict terms of stimulating local economic growth, they may be losing sight of the larger and potentially more significant economic importance of NPS sites. Economic benefits accruing to park visitors, and spending associated with those visits, is threatened by degradation of NPS sites caused by rapid development. Second, in order to man-

age the growth that is occurring, local, state, and federal government will need to work together to develop smart growth plans. The overlap of these three government jurisdictions around NPS sites creates a challenge for planning that will likely need to be tackled head on in the very near future. Failing to embrace these two policy imperatives could easily result in economic loss.

**Conclusion**

Both the peer-reviewed academic literature and our selected case studies demonstrate that economic growth near national parks outpaces other areas that lack similar natural amenities. While growth also depends on other factors, such as infrastructure and accessibility, the case is becoming clear that national parks play an important role in stimulating regional economies. Indeed, arguments that protected areas inhibit growth by making valuable natural resources unavailable to extractive industries such as mining and forestry have proven unfounded. Growth is often higher near protected areas, and the diversity and quality of business growth may be greater especially with regard to knowledge-based jobs.

Growth also brings challenges. Some communities near parks suffer from increasing wealth polarization and falling housing affordability. In other communities, growth is beginning to impinge on the natural amenities that first attracted most in-migrants. An important lesson is that an exclusive focus on economic growth as the main economic contribution of NPS sites loses sight of the other economic benefits they generate and that must be protected. To the extent that growth diminishes these benefits, a real cost is incurred by our nation. It is easy to see that a slight deterioration in visitor experience can generate very large social costs. For this reason, growth should be considered one element of the economic importance of NPS sites that must be balanced among the others, and its potentially negative effects must be managed.

# Chapter 5: Case Study Sites

**TABLE 11: OVERVIEW OF NPS SITES SELECTED FOR CASE STUDY**

| *NPS Sites* | *Site Type* | *Region* | *State* | *Location* | *Visitation 2004*[1] | *Base Funding FY2004*[2] *($mil)* |
|---|---|---|---|---|---|---|
| **Acadia** | National Park | Northeast | ME | Rural | 2,207,847 | $6.3 |
| **Apostle Islands** | National Lakeshore | Midwest | WI | Remote | 151,881[3] | $2.4 |
| **Biscayne** | National Park | Southeast | FL | Rural | 478,304 | $3.4 |
| **Denali** | National Park | Alaska | AK | Rural | 404,236 | $10.7 |
| **Fort Sumter** | National Monument | Southeast | SC | Outlying Metropolitan | 781,239 | $1.8 |
| **Gettysburg** | National Military Park | Mid-Atlantic | PA | Outlying Metropolitan | 1,724,420 | $5.2 |
| **Joshua Tree** | National Park | Southwest | CA | Rural | 1,243,659 | $4.1 |
| **Point Reyes** | National Seashore | Pacific West | CA | Outlying Metropolitan | 1,960,055 | $4.9 |
| **Rocky Mountain** | National Park | Mountain West | CO | Outlying Metropolitan | 2,781,899 | $10.3 |
| **Sequoia & Kings Canyon** | National Park | Pacific West | CA | Rural | 1,525,212 | $12.9 |
| **Shenandoah** | National Park | Mid-Atlantic | VA | Rural | 1,261,000 | $10.2 |
| **Zion** | National Park | Southwest | UT | Rural | 2,677,342 | $6.0 |
| ***Total*** | *8 NP, NL, NS NM, NMP* | *Nearly all regions represented* | *10 different states* | *8 rural, 4 outlying metropolitan* | *150,000 to 2.8 million* | *5 sites: < $5mil 3 sites: $5-10mil 4 sites: >$10mil* |

[1] Visitation indicates number of visits to NPS site. Source: National Park Service Statistical Abstract 2004.
[2] Reflects base funding for the operation of the NPS site; total park funding may be higher. Source: U.S. Department of the Interior, Budget Justifications and Performance Information FY2006, National Park Service ("Greenbook").
[3] Visitation number believed to be an underestimate due to multiple unmonitored entry points to site.

To illustrate the economic significance of national parks, we selected 12 NPS sites for case-level analysis. These sites represent a diversity of geographic locations, types of sites (resource-based and historic), annual visitation levels, proximity to population centers, and levels of funding. This section provides a one-page summary of each site's economic benefits, impacts, growth trends, budget shortfalls, and priority needs, as well as assesses each site's benefit to cost ratio and threshold at which funding the budget shortfall is justified. Table 11 describes the sites selected for case-level analysis.

Key terms and concepts applied in assessing the economic significance of each NPS site are described below.

- *Economic Benefits* refer to total value people derive from national parks through direct and passive use. This study only captures economic benefits of recreation. Other values (e.g., ecosystem services, education/science, passive use) could not be estimated due to a variety of challenges. Therefore, park benefit estimates should be viewed as conservative. Across the 12 sites, annual recreational benefits range from $7 million (Apostle Islands and Fort Sumter) to over $100 million (Acadia, Point Reyes, and Rocky Mountain).

- *Benefit to Cost Ratio* reflects the degree to which a park's (recreational) benefits exceed expenditures to maintain the site. Across the sites, benefit to cost ratios are all greater than 1, ranging from 1.4 (Denali) to 14.1 (Acadia and Point Reyes).

- *Economic Impacts* measure park visitor spending and its effects on sales/output, employment, income, and value-added in the surrounding area. Visitor spending and the corresponding impacts are greater for sites with higher visitation levels and park area spending opportunities (Rocky Mountain and Acadia).

- *Economic Growth* refers to trends occurring due to economic activity associated with proximity to parks. That is, for some sites, park amenities may contribute to attracting new businesses and residents (and retaining old ones). Indicators for assessing growth trends in areas surrounding parks include changes in population, employment, personal income, earnings per job, and housing affordability. For the seven sites for which data allow economic growth analysis (1970-2003), annual average growth in population, employment, and personal income outpace averages for the states in which the sites are located. Earnings per job increase more slowly across the sites, while housing affordability in most cases does not decline, and more generally follows state-wide trends.

- *Budget Shortfalls and Park Needs* are identified in the most recent business plans of each park, developed under the NPS's *Business Plan Initiative*. The average annual budget shortfall is just over $5 million per park, ranging from a low of about $1 million (Biscayne) to a high of $15 million (Sequoia & Kings Canyon). In general, the parks need this funding to address priorities in resource protection, facility maintenance, and visitor services and safety.

- *Threshold Analysis* indicates the degree of change in park quality

that would justify an increase in spending, keeping in mind that such an increase may either prevent degradation of the park or might improve overall conditions. This threshold reflects a park's budget shortfall as a percentage of the park's economic (recreational) benefits. Across 12 sites, the threshold to justify proposed budget increases varies from a low of 2.7 percent (Rocky Mountain) to a high of 54 percent (Apostle Islands).

## Acadia National Park

Located along the coast of Maine, Acadia National Park comprises approximately 35,000 acres, most of which are located on Mount Desert Island. Scenic highlights of the park include its rocky coast, mountains, lakes, and glaciated valleys. Over two million people visited the park in 2004. Recreational activities include hiking, picnicking, mountain biking, bird watching, rock climbing, camping, boating, canoeing, and kayaking. Highlights of the park's economic importance include:

- $100 million in annual recreational benefits, providing a park benefit to cost ratio of more than 14 to 1.
- $137 million in annual visitor spending, supporting more than 3,500 local jobs (not including park staff).
- Amenity values contributing to annual population, employment, and personal income growth rates 0.5% to 1% higher than the state average.

Acadia's most recent business plan (FY2000) indicates an annual budget shortfall of $8.0 million (adjusted to 2004 dollars). This funding is needed for upgrading utilities and campgrounds, rehabilitating bridges and trails, completing boundary surveys and carrying capacity studies, and restoring disturbed habitats. Applying a threshold analysis, Acadia's budget shortfall represents 8.0% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 6 to 1.

**Acadia National Park – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 2,207,847 | $100.4 | Not quantified | $7.1 | >14.1 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $137.1 | $172.8 | $61.7 | 3,556 | $97.0 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| *Local* | 1.3 | 2.9 | 3.2 | $27.3 | 103 to 141 | More |
| *State* | 0.8 | 1.8 | 2.6 | $33.5 | 110 to 162 | More |
| *Difference* | 0.5 | 1.1 | 0.6 | -$6.1 | | Same |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Apostle Islands National Lakeshore

Located at the northernmost tip of Wisconsin, Apostle Islands National Lakeshore encompasses over 750 square miles of Lake Superior and its shoreline. The park includes a 21 island archipelago, as well as 12 miles of mainland shoreline and adjacent lake waters. More than 150,000 people visited the park in 2004. Recreational activities include walking beaches, swimming, kayaking, and boating. Highlights of the park's economic importance include:

- $6.8 million in annual recreational benefits, providing a park benefit to cost ratio of at least 2.6 to 1.
- More than $7 million in annual visitor spending, supporting nearly 200 local jobs (not including park staff).
- Amenity values contributing to population, employment, and personal income growth higher than the state average.

Apostle Islands' most recent business plan (FY2001) shows an annual budget shortfall of $3.7 million (adjusted to 2004 dollars). This funding is needed to address maintenance, safety and security, habitat restoration, control of non-native species, cultural resource planning, and archeological research. Applying a threshold analysis, Apostle Islands' budget shortfall represents 54% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 1 to 1.

**Apostle Islands National Lakeshore – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 151,881[2] | $6.8 | Not quantified | $2.6 | >2.6 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $7.5 | $7.9 | $2.7 | 195 | $4.3 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| *Local* | 0.8 | 2.1 | 2.6 | $19.3 | 163 to 163 | Same |
| *State* | 0.6 | 1.7 | 2.1 | $37.6 | 167 to 167 | Same |
| *Difference* | 0.2 | 0.4 | 0.5 | -$18.3 | | Same |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.
[2] Visitation number believed to be an underestimate due to multiple unmonitored entry points to site.

## Biscayne National Park

Biscayne National Park is located in the southeastern region of the Florida peninsula and encompasses much of Biscayne Bay, making it the largest marine park in the National Park System. The park protects part of the third-largest coral reef system in the world and the longest stretch of mangrove forest remaining on Florida's east coast. Nearly 500,000 people visited the park in 2004. Recreational activities include nature viewing, walking and hiking, fishing, boating, swimming, diving and snorkeling, picnicking, and camping. Highlights of the park's economic importance include:

- $19 million in annual recreational benefits, providing a park benefit to cost ratio of more than 5 to 1.
- $24 million in annual visitor spending, supporting 425 local jobs (not including park staff).

*State of the Parks: Biscayne National Park* (2006) indicates an annual budget shortfall of approximately $0.8 million. Funding is needed to maintain core staffing and visitor service levels, support essential operating needs, restore law enforcement and maintenance capabilities, and ensure resource protection. Applying a threshold analysis, Biscayne's budget shortfall represents 3.9% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 4 to 1.

**Biscayne National Park – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 478,304 | $19.1 | Not quantified | $3.4 | >5.5 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $24.0 | $28.9 | $11.3 | 425 | $17.7 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| NA | Growth trends are not analyzed because the park's close proximity to an urban area (Miami) creates a high potential for confounding park-led growth with other factors. | | | | | |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Denali National Park and Preserve

Encompassing six million acres of sub-arctic Alaska, Denali National Park and Preserve is larger than the state of Massachusetts. And with only one 92-mile road, wilderness is the park's defining experience. Denali (Athabaskan name) or Mount McKinley is the park's most famous feature. At 20,320 feet, it is the highest peak in North America and the centerpiece of the Alaska Range. The park's main recreational activities are wildlife viewing, hiking, and camping. Highlights of the park's economic importance include:

- $20.0 million in annual recreational benefits, providing a park benefit to cost ratio greater than 1.4 to 1.
- About $23 million in annual visitor spending, supporting over 500 jobs (not including park staff). However, this spending estimate appears to be quite conservative. Adjustments to the analysis of visitor spending suggest total spending by Denali visitors may be well over $100 million (Chapter 3).

Denali's 2004 business plan indicates an annual budget shortfall of $3.9 million. This funding is needed to address resource protection priorities, visitor safety services, facility operations and maintenance, and support education and interpretation programs. Applying a threshold analysis, Denali's budget shortfall represents 19.6% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 1.1 to 1.

**Denali National Park and Preserve – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 404,236 | $20.0 | Not quantified | $14.1 | >1.4 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $22.7 | $27.1 | $9.7 | 562 | $15.4 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| NA | Insufficient data. Park amenity values are unlikely to be a major factor in growth trends. | | | | | |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Fort Sumter National Monument

Located on a small island near the city of Charleston, South Carolina, Fort Sumter is the place where the Civil War began on April 12, 1861. The site contains more than 40 historic structures including Fort Sumter, Fort Moultrie, the Major Robert Anderson monument, and Battery Huger. Nearly 800,000 people visited this historic site in 2004. Highlights of the park's economic importance include:

- Over $7 million in annual recreational benefits, providing a park benefit to cost ratio greater than 4 to 1.
- About $18 million in annual visitor spending, supporting nearly 400 jobs (not including park staff).

A business plan for Fort Sumter was not available for this analysis. According to park management plans, a chief concern for the park is historic/cultural asset management, to minimize the loss or degradation of culturally significant material. However, we did not identify any specific information on budget shortfalls or investment needs.

**Fort Sumter National Monument – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 781,239 | $7.1 | Not quantified | $1.8 | >4.0 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $17.8 | $20.0 | $7.6 | 391 | $12.0 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| NA | Growth trends are not analyzed because the park's close proximity to an urban area (Charleston) creates a high potential for confounding park-led growth with other factors. | | | | | |

[1] Other park benefits not quantified include passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Gettysburg National Military Park

Gettysburg National Military Park preserves and commemorates the historically significant site of the Battle of Gettysburg, the largest and most costly in human lives to occur in North America. The park encompasses 6,000 acres in south central Pennsylvania and preserves more than 1,300 monuments. Over 1.7 million people visited the park in 2004. Highlights of Gettysburg's economic importance include:

- Over $15 million in annual recreational benefits, providing a park benefit to cost ratio greater than 2.2 to 1.
- More than $95 million in annual visitor spending, supporting close to 3,000 jobs (not including park staff).
- Amenity values contributing to annual population, employment, and personal income growth rates more than one percent higher than the state average.

Gettysburg's most recent business plan (FY2001) shows an annual budget shortfall of $3.8 million (adjusted to 2004 dollars). This funding is needed for preserving archival and museum collections, historic structures, and historic landscapes, meeting demand for interpretation and education programs, and improving services. Applying a threshold analysis, Gettysburg's budget shortfall represents 24% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 1.4 to 1.

**Gettysburg National Military Park – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 1,724,420 | $15.6 | Not quantified | $7.0 | >2.2 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $95.2 | $112.3 | $37.5 | 2,851 | $59.7 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| *Local* | 1.6 | 2.2 | 2.9 | $27.9 | 128 to 157 | More |
| *State* | 0.1 | 0.9 | 1.7 | $41.9 | 150 to 179 | More |
| *Difference* | 1.5 | 1.3 | 1.2 | -$14.0 | | Same |

[1] Other park benefits not quantified include passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Joshua Tree National Park

Located 140 miles east of Los Angeles and comprising nearly 800,000 acres, Joshua Tree National Park includes two important desert ecosystems, the Colorado and Mojave Deserts. More than 1.2 million people visited the park in 2004. Recreational activities include hiking and walking self-guided nature trails, camping, bouldering, stargazing/viewing the night sky, and visiting historical and archeological sites. Highlights of the park's economic importance include:

- $48 million in annual recreational benefits, providing a park benefit to cost ratio of at least 7.5 to 1.
- Annual visitor spending of $49 million, supporting over 1,100 local jobs (not including park staff).

The most recent business plan for Joshua Tree (FY2001) shows an annual budget shortfall of $2.8 million (adjusted to 2004 dollars). This funding is needed to address resource preservation and management needs, visitor access, safety, and services, and external challenges pertaining to urban encroachment. These include development of groundwater storage projects, mega-landfills, hydroelectric- and gas-fired power plants, and mining operations adjacent to the park. Applying a threshold analysis, Joshua Tree's budget shortfall represents 5.9% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 5 to 1.

**Joshua Tree National Park – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 1,243,659 | $47.9 | Not quantified | $6.4 | >7.5 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $49.3 | $62.3 | $23.2 | 1,152 | $36.6 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| NA | Park is located in the largest county (San Bernardino) in the contiguous U.S. A county-level growth analysis would have high potential for confounding park-led growth with other factors. | | | | | |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Point Reyes National Seashore

Point Reyes National Seashore encompasses over 71,000 acres, including 33,000 acres of wilderness area and 80 miles of undeveloped coastline. The park provides an important link in a chain of protected areas, which combined constitute one of the few remaining biologically diverse Mediterranean climate regions on earth. Located about one hour's drive from the San Francisco Bay Area, the park received about two million visitors in 2004. Recreational opportunities include 147 miles of hiking trails, four back country campgrounds, and numerous beaches. Highlights of the park's economic importance include:

- More than $120 million in annual recreational benefits, providing a park benefit to cost ratio greater than 14 to 1.
- Annual visitor spending of $89 million, supporting over 2,000 local jobs (not including park staff).

The most recent business plan for Point Reyes (FY2002) indicates an annual budget shortfall of $5.2 million (adjusted to 2004 dollars). This funding is needed to address maintenance of facilities and trails, enhancement of visitor services, control of non-native species, protection of endangered species, and reduction of threats to cultural resources. Applying a threshold analysis, Point Reyes' budget shortfall represents 4.3% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 8.8 to 1.

**Point Reyes National Seashore – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 1,960,055 | $121.6 | Not quantified | $8.6 | >14.1 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $89.0 | $111.0 | $41.5 | 2,065 | $65.4 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| NA | Growth trends are not analyzed because the park's close proximity to an urban area (San Francisco) creates a high potential for confounding park-led growth with other factors. | | | | | |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Rocky Mountain National Park

Located in north central Colorado, Rocky Mountain National Park preserves 416 square miles of alpine environment, including 114 peaks over 10,000 feet and scenic features including canyons, glaciers, and the headwaters of the Colorado River. Recreational activities include hiking, wildlife viewing, fishing, scenic drives, and camping. Highlights of the park's economic importance include:

- More than $130 million in annual recreational benefits, providing a park benefit to cost ratio greater than 8.4 to 1.
- $194 million in annual visitor spending, supporting over 5,000 local jobs (not including park staff).
- Amenity values contributing to annual population, employment, and personal income growth more than one percent higher than the state average.

Rocky Mountain's most recent business plan (FY1998) shows a budget shortfall of $3.5 million (adjusted to 2004 dollars). Likewise, State of the Parks: Rocky Mountain National Park (2002) estimates a budget shortfall for FY 2000 of about $3 million (2004 dollars). This funding is needed for facility maintenance, safety and services, elk and vegetation management, and research, planning, and monitoring. Applying a threshold analysis, Rocky Mountain's shortfall represents 2.7% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 6.8 to 1.

**Rocky Mountain National Park – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 2,781,899 | $132.6 | Not quantified | $15.8 | >8.4 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $193.6 | $209.3 | $71.1 | 5,178 | $112.6 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| *Local* | 3.3 | 4.9 | 5.6 | $37.0 | 130 to 121 | Less |
| *State* | 2.2 | 3.2 | 4.0 | $43.6 | 129 to 119 | Less |
| *Difference* | 1.1 | 1.7 | 1.6 | -$6.7 | | Same |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Sequoia and Kings Canyon National Parks

Sequoia and Kings Canyon National Parks are home to giant sequoia groves, the largest trees in the world. Located in central California, the parks encompass 1,352 square miles, extending from the Sierra foothills to 14,494 feet at the summit of Mount Whitney – the highest peak in the contiguous 48 states. In 2004, the parks received 1.5 million visitors. Recreational activities include hiking, wildlife viewing, camping, swimming, and touring caves. Highlights of the park's economic importance include:

- Over $58 million in annual recreational benefits, providing a park benefit to cost ratio greater than 2.5 to 1.
- $74 million in annual visitor spending, supporting close to 2,000 local jobs (not including park staff).

Sequoia and Kings Canyon's business plan (FY2002) shows a budget shortfall of $14.8 million (adjusted to 2004 dollars). This funding is needed for resource protection, deterring marijuana cultivation, biodiversity research/monitoring, fire program support, facility and trail maintenance, communications, and road rehabilitation. Applying a threshold analysis, the parks' shortfall represents 25% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the parks would still maintain an annual benefit to cost ratio greater than 1.5 to 1.

**Sequoia and Kings Canyon National Parks – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 1,525,212 | $58.6 | Not quantified | $23.1 | >2.5 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $73.9 | $102.2 | $39.5 | 1,882 | $61.3 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| *Local* | 2.2 | 2.6 | 3.0 | $34.9 | 107 to 132 | More |
| *State* | 1.7 | 2.4 | 2.9 | $47.5 | 62 to 89 | More |
| *Difference* | 0.5 | 0.2 | 0.1 | -$12.6 | | Same |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Shenandoah National Park

Comprising 300 square miles of the Blue Ridge Mountains, Shenandoah National Park rises 3,500 feet above the Shenandoah valley in northern Virginia. Located 80 miles west of Washington, D.C., the park offers a rolling landscape of hardwood forests and historic farms, while protecting a sizeable portion of the Blue Ridge/ Central Appalachian biome – one of the world's most diverse temperate ecosystems. The park received more than 1.2 million visitors in 2004. Recreational activities include viewing scenic overlooks, hiking, camping, wildlife viewing, and visiting historic sites. Highlights of the park's economic importance include:

- $70 million in annual recreational benefits, providing a park benefit to cost ratio greater than 4.4 to 1.
- $44 million in annual visitor spending, supporting over 1,000 local jobs (not including park staff).

Shenandoah's most recent business plan (FY2003) shows a budget shortfall of $8.0 million (adjusted to 2004 dollars). Increased funding is needed to protect natural and cultural resources, maintain facilities and trails, rehabilitate overlooks, and support interpretation and education programs. Applying a threshold analysis, Shenandoah's budget shortfall represents 11.5% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 2.9 to 1.

**Shenandoah National Park – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 1,261,000 | $70.0 | Not quantified | $15.7 | >4.4 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $43.9 | $55.1 | $20.5 | 1,010 | $32.3 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| *Local* | 1.9 | 2.1 | 3.6 | $25.5 | 131 to 151 | More |
| *State* | 1.4 | 2.4 | 3.4 | $43.9 | 125 to 153 | More |
| *Difference* | 0.5 | -0.3 | 0.2 | -$18.3 | | Same |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

## Zion National Park

Zion National Park is characterized by multi-colored cliffs, deep canyons, high plateaus, striking rock towers and mesas, and the Virgin River. Located in southwest Utah, the park encompasses about 150,000 acres, rising from an elevation of 3,600 feet to 8,700 feet. More than 2.6 million people visited the park in 2004. Recreational activities include scenic viewing, hiking, wading in the river, picnicking, and camping. Highlights of the park's economic importance include:

- Close to $100 million in annual recreational benefits, providing a park benefit to cost ratio greater than 10.5 to 1.
- $83 million in annual visitor spending, supporting over 2,000 local jobs (not including park staff).
- Amenity values contributing to annual population, employment, and personal income growth more than 2.5 percent higher than the state average.

Zion's most recent business plan (FY2000) shows a budget shortfall of $4.8 million (adjusted to 2004 dollars). This funding is needed for major investments in rehabilitating the water system, campgrounds, and roads, constructing an emergency operations center, and conducting an inventory of natural and cultural resources. Applying a threshold analysis, Zion's budget shortfall represents 4.9% of annual recreational benefits. Funding the shortfall is justified where it would increase park benefits, or prevent losses in park benefits, by this amount. Even if the funding only prevented losses in benefits, the park would still maintain an annual benefit to cost ratio greater than 6.9 to 1.

**Zion National Park – Overview of Economic Importance**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Economic Benefits (2004)** | *Visitation* | *Total Recreational Benefits ($mil)* | *Other Benefits*[1] | *Annual Budget ($mil)* | *Benefit to Cost Ratio*[1] | |
| | 2,677,342 | $98.6 | Not quantified | $9.4 | >10.5 to 1 | |
| **Economic Impacts (2004)** | *Visitor Spending ($mil)* | *Sales ($mil)* | *Personal Income ($mil)* | *Jobs* | *Value Added ($mil)* | |
| | $83.1 | $95.4 | $34.7 | 2,013 | $54.7 | |
| **Economic Growth** | *Annual Population Growth 1970-2003* | *Annual Employment Growth 1970-2003* | *Annual Personal Income Growth 1970-2003* | *Median Earnings per Job 2003* | *Housing Affordability: Index and Affordability Trend 1990-2000*[3] | |
| | *(%)* | *(%)* | *(%)* | *($'000)* | *1990-2000* | *Trend* |
| *Local* | 5.2 | 6.2 | 6.5 | $25.7 | 112 to 109 | Less |
| *State* | 2.4 | 3.5 | 3.9 | $35.0 | 143 to 124 | Less |
| *Difference* | 2.8 | 2.7 | 2.6 | -$9.3 | | Same |

[1] Other park benefits not quantified include ecosystem services, biodiversity, science, education, cultural, spiritual, and passive use values. The benefit-cost ratio is conservative; it only reflects recreational benefits.

# Chapter 6: Next Steps

The findings presented in this study build upon the work of a number of researchers who have endeavored to capture the economic significance of the U.S. National Park System from a variety of angles. We conclude that national parks play an important role in local economies as well as the national economy. Policy makers at all levels should be aware of this, and carefully consider the potential benefits and costs of budgetary decisions that will affect NPS sites in the future.

In an effort to make this report as objective as possible, and to support informed decision making and structured debate on the merits of public funding for NPS, we have made every attempt to clearly describe our methods and assumptions. In some cases those assumptions can be challenged and alternative estimates may be made. To make such a process as constructive as possible, the spreadsheets and more complete description of our approach are available upon request.

In addition, we believe that further study of the economic significance of the national park system could yield more robust estimates of greater precision. We have identified weaknesses in current methods and data throughout the body of the report. Following is a list of suggestions for additional study that will help to fill those gaps.

- *Case Studies:* This report includes a cross section of case studies. Additional case studies will be useful in building a richer understanding of the characteristics of the full range of NPS sites. In order to do so effectively, base documents, including business plans, visitor surveys, and examinations of site needs are very helpful.

- *Effects of Budget Shortfalls:* Cost-benefit analysis of the park system could be greatly fortified by a more comprehensive examination of the effects on parks of budget shortfalls. This should include the physical and ecological changes that result from insufficient budgets, today and over time. Once completed, economic analysis will be required to evaluate the economic benefits of improvements, or avoidance of deterioration, of park quality.

- *Impact Analyses:* MGM2 currently produces conservative and defensible estimates of the impacts of local economic activity attributable to park visitation. Efforts to extend the inclusiveness of site-specific spending patterns for more NPS sites, as well as inclusion of broader geographic areas of park-related spending could make estimates more accurate.

- *Historic Sites:* A major subset of NPS sites are historic, but there has been very little primary research conducted on the benefits associated with preserving these sites and making them available for public visitation. Additional visitor survey research should be a priority for improving estimates of the economic benefits of historic sites.

Despite a list of substantive work that could be done to improve our current estimates of the park system's economic significance, we do not envision a scenario where additional research could alter the conclusions of this report. The U.S. National Park System provides national economic benefits far in excess of the public cost of maintaining and operating them, and parks are an important engine for local jobs and income and are a substantial driver of economic growth. Federal support of NPS is a wise economic investment.

# References


Dearien, C., G. Rudzitis, and J. Hintz. 2005. The role of wilderness and public land amenities in explaining migration and rural development in the American Northwest. In eds. Green, G., S. Deller, D. Marcouiller. 2005. *Amenities and Rural Development: Theory, Methods and Public Policy*. EE: Northhampton, MA.

Duffy-Deno, K. 1998. The Effect of Federal Wilderness on County Growth in the InterMountain United States. *Journal of Regional Science*, 38(1):109-136.

Green, G., S. Deller, and D. Marcouiller. 2005. *Amenities and Rural Development: Theory, Methods and Public Policy*. EE: Northhampton, MA.

Kaval, P., and J. Loomis. 2003. Updated Outdoor Recreation Use Values with Emphasis on National Park Recreation. Report to National Park Service, Fort Collins, CO, under Cooperative Agreement CA 1200-99-009, Project Number IMDE-02-0070.

Krutilla, J. 1967. Conservation Reconsidered. *American Economic Review* 57:787-796.

Le, Y., M. Littlejohn, and S. Hollenhorst. 2004. Joshua Tree National Park Visitor Study, Spring 2004. Visitor Services Project, Report 152, December 2004.

Leggett, C., N. Kleckner, K. Boyle, J. Duffield, and R. Mitchell. 2003. "Social Desirability Bias in Contingent Valuation Surveys Administered Through In-Person Interviews." *Land Economics*, 79(4):561-565.

Littlejohn, M. 1999. Acadia National Park Visitor Study, Summer 1998. Visitor Services Project, Report 108, May 1999.

Longwoods International. 2005. Travel and Tourism in Maine: The 2004 Visitor Study Management Report. Prepared for the Maine Office of Tourism, July 14, 2005.

Loomis, J. 2000. Economic Values of Wilderness Recreation and Passive Use: What We Think We Know at the Beginning of the 21st Century. *USDA Forest Service Proceedings, RMRS-P-15* Vol. 2: 5-13.

Lorah, P. 2000. Population Growth, Economic Security, and Cultural Change in Wilderness Counties. USDA Forest Service Proceedings RMRS-P-15 Vol. 2: 230-237.

Lorah, P. and R. Southwick. 2003. Environmental Protection, Population Change, and Economic Development in the Rural Western United States. *Population and Environment* 24(3):255-271.

Machlis, G. and D. Field, eds. 2000. *National Parks and Rural Development: Practice and Policy in the United States*. Island Press: Washington, DC.

McGranahan, D. 1999. Natural amenities drive rural population change. Agricultural Economic Report. 781. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Money Generation Model 2. 2003. Impact reports. http://web4.canr.msu.edu/MGM2/

National Park Service. 2004. Statistical Abstract 2004. Public Use Statistics Office. Denver, CO.

National Parks Conservation Association. 2002. *State of the Parks: Rocky Mountain National Park – A Resource Assessment*. Washington, DC.

National Parks Conservation Association. 2003. *Gateway to Glacier: The Emerging Economy of Flathead County*. Washington, DC.

National Parks Conservation Association. 2006. *State of the Parks: Biscayne National Park – A Resource Assessment*. Washington, DC.

Northern Economics. 2002. Alaska Visitor Expenditures and Opinions, Summer 2001. Prepared for State of Alaska, Department of Community & Economic Development, November 2002.

Rasker, R., B. Alexander. 2003. Getting Ahead in Greater Yellowstone: Making the Most of Our Competitive Advantage. Published by Sonoran Institute and Yellowstone Business Partnership.

Rasker, R., A. Hansen. 2000. Natural Amenities and Population Growth in the Greater Yellowstone Region. *Research in Human Ecology* 7(2):30-40.

Rosen, H. 1988. *Public Finance* (Second Edition). Irwin Publishers, Homewood, Ill.

Schmidt, L. and P. Courant. 2005. Sometimes Close is Good Enough: The Value of Nearby Environmental Amenities. Williams College, MA. Draft manuscript.

Sedell, J., M. Sharpe, D. Dravnieks Apple, M. Copenhagen, M. Furniss. 2000. Water & The Forest Service. USDA Forest Service Policy Analysis, Washington, DC.

Sonoran Institute. 2004. Public Lands Conservation and Economic Well-Being. www.sonoran.org.

Stynes, D. and Y. Sun. 2003. Economic Impacts of National Park Visitor Spending on Gateway Communities Systemwide Estimates for 2001. Michigan State University. http://web4.canr.msu.edu/MGM2

University of Idaho, Park Studies Unit, Visitor Services Project. http://www.psu.uidaho.edu/vsp.reports.htm

USDA Forest Service (Garber-Yonts, B.). 2004. The Economics of Amenities and Migrations in the Pacific Northwest: Review of Selected Literature with Implications for National Forest Management. General Technical Report PNW-GTR-617.

U.S. Department of Interior. 2006. Budget Justifications and Performance Information Fiscal Year 2006: National Park Service. Washington, DC.

U.S. Government Accountability Office. 2006. National Park Service: Major Operations Funding Trends and How Selected Park Units Responded to Those Trends for Fiscal Years 2001 through 2005. GAO-06-431, Washington, DC.

# Appendix: Key Project Steps and Sources

This appendix provides an overview of steps taken to carry out the study and key sources of information. To begin, we conducted an extensive literature review of more than one hundred studies addressing the economic role of protected lands, including national parks and wilderness areas. This review was complemented by interviews with 30 experts from academia, the National Park Service and other government agencies, non-governmental organizations, and the private sector to gain their perspectives on the economic role of national parks (Box A-1).

Based on the literature review and expert interviews, we determined that providing the most complete picture of the park system's economic importance would require analysis of three types of economic measures: *economic benefits* generated by the parks, *economic impacts* of park visitation, and the *economic growth patterns* associated with parks. Our approach and data sources for these analyses are described briefly below.[13]

**Economic Benefit Analysis**

Economic benefit measures the total value that people derive from the national park system through direct and passive use. We determined through the literature review and expert interviews that, while extensive data were available on recreational values associated with protected lands, quantitative estimates of other types of benefits (e.g., ecosystem services, biodiversity, research/education, cultural/spiritual values, and passive use values) were either quite limited or did not exist. Focusing on recreational use, we identified a number of important sources for conducting our analysis, including:

- *Database of Recreational Value Estimates* (Kaval and Loomis 2003) – This database compiles 1,239 estimates of recreational value from 593 studies. These estimates span 30 separate outdoor recreational activities, including wildlife viewing, sightseeing, hiking, and so on.

- *Visitor Study Surveys* (University of Idaho, Park Studies Unit, Visitor Services Project. http://www.psu.uidaho.edu/vsp.reports.htm) – Among other information, these surveys provide data on the most common activities engaged in by park visitors.

- *National Park Business Plans* (Business Plan Initiative, www.nps.gov) – The National Park Service, in partnership with the National Parks Conservation Association, developed the business plan initiative to support analysis of park operations. Parks that have developed a business plan provide a financial summary of their current budget, as well as estimates of their current budget shortfalls and priority needs.

- *State of the Parks* (National Parks Conservation Association, www.npca.org) – The National Parks Conservation Association initiated these studies to assess the condition of natural and cultural resources in the parks, and to determine how well equipped the National Park Service is to protect the parks.

These sources allowed for cost-benefit analysis of the National Park System, where costs reflect the park system budget and benefits reflect recreational values associated with park visitation. For our case study sites, we identified the range of recreational activities engaged in at each site (based on Visitor Study Survey information), and weighted recreational estimates from the Kaval and Loomis database accordingly. Information on the current budgets, shortfalls, and priority needs for case study sites was drawn from park business plans and/or State of the Parks reports, where available.

**Economic Impact Analysis**

Economic impact analysis measures park visitors' spending and the effects it has on a town or county's output, employment, and income. The National Park Service currently supports the *Money Generation Model 2* (MGM2) to estimate economic impacts of each park and the overall system. MGM2 estimates economic impacts by multiplying the number of park visitors by average spending per visitor and regional economic multipliers.

Our study's economic impact estimates reflect the most recent MGM2 model estimates, with case study site estimates drawn from http://web4.canr.msu.edu/MGM2/. Based on our analysis of case study sites, we identified some instances where MGM2 estimates appear quite conservative (e.g., Denali). These cases are highlighted along with potential opportunities for refining and extending impact analysis for the parks.

**Economic Growth Analysis**

Economic growth analysis measures trends occurring as a result of economic activity associated with proximity to parks. Such economic activity extends beyond tourism to include all economic activity attracted to an area by the natural amenities provided by the park. For this study, we drew upon a range of existing studies of the relationship

[13] Spreadsheets showing calculations for each analysis are available upon request.

between protected lands and economic growth. In addition, we conducted analysis of our case study sites using the Bureau of Land Management and Sonoran Institute Economic Profile System (www.sonoran.org). We analyzed the growth in population, employment, income, earnings per job, and housing affordability in counties surrounding or adjacent to the park site compared to state-wide averages from 1970 to 2003.

**Box A-1: Experts Interviewed for Study**

1. **Hana Blake** Community Planning Director, Erie Canal Heritage Corridor
2. **Fred Boyles** Superintendent, Andersonville National Historic Site
3. **Steve Colt** Associate Professor of Economics, University of Alaska Anchorage
4. **Suzanne Copping** Assistant Coordinator, National Heritage Areas, National Park Service
5. **Ginny Fay** Eco-Systems (former Alaska State Tourism Director)
6. **Kate Fox** Essex National Heritage Area
7. **Mary Goundrey** Civil War Preservation Trust
8. **Jim Gramann** Visiting Chief Social Scientist, National Park Service
9. **Howard Gross** California Desert Program Manager, National Parks Conservation Association
10. **John Howard** Superintendent, Antietam National Battlefield
11. **Bill Jackson** Director of Water Resources Division, National Park Service
12. **Grace Johns** Senior Natural Resource Economist, Hazen and Sawyer
13. **John Kelly** Planning Director, Acadia National Park
14. **Chris Leggett** Senior Associate, Industrial Economics, Incorporated
15. **John Loomis** Professor, Department of Agricultural and Resource Economics, Colorado State University
16. **Paul Lorah** Professor and Chair, Department of Geography, University of St. Thomas (St. Paul, MN)
17. **Pete Morton** Economist, The Wilderness Society
18. **Tom Offut** Trustee, Yellowstone Park Foundation
19. **Kyle Patterson** Public Information Officer, Rocky Mountain National Park
20. **Bruce Peacock** Economist, National Park Service
21. **Alexandra Picavet** Public Affairs Specialist, Sequoia and Kings Canyon National Parks
22. **Thomas Power** Professor and Chair, Department of Economics, University of Montana
23. **Ray Rasker** Senior Economist, Sonoran Institute
24. **Gundars Rudzitis** Professor, Department of Geography, University of Idaho
25. **Lucie Schmidt** Assistant Professor of Economics, Williams College
26. **Jim Stratton** Alaska Regional Director, National Parks Conservation Association
27. **Butch Street** Public Use Statistics Office, National Park Service
28. **Daniel Stynes** Professor Emeritus, Department of Park, Recreation and Tourism Resources, Michigan State University
29. **Bob Unsworth** President, Industrial Economics, Incorporated
30. **Joe Zarki** Joshua Tree National Park

# EXHIBIT 10

HEADWATERS ECONOMICS | Land and Communities

# National Park Service Units:
## Economic Impacts of Visitation and Expenditures

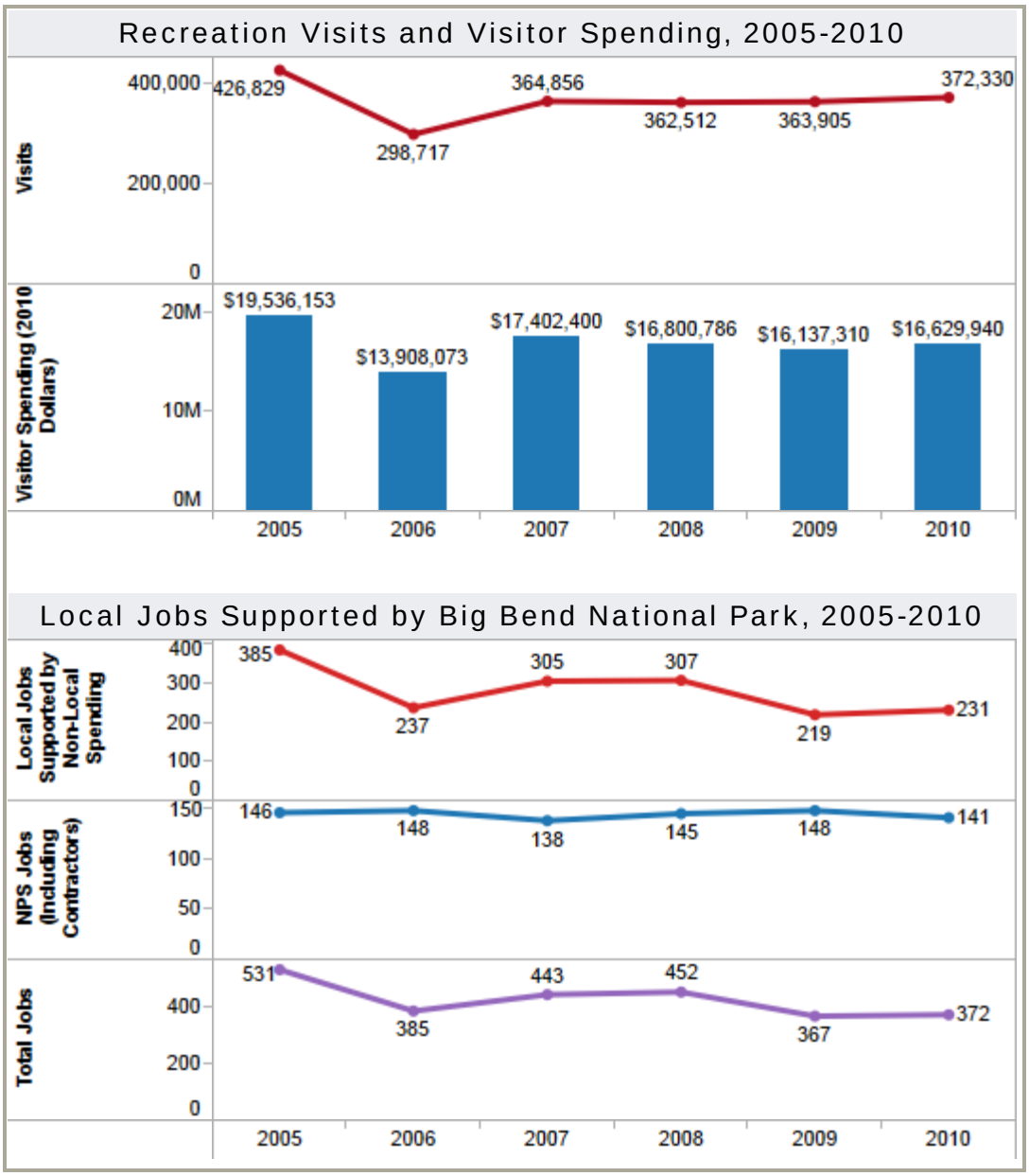
RELATED RESEARCH
The Value of Protected Lands
Socioeconomic Profiles

**Step 1:**
**Select One or More Par..**

- [ ] (All)
- [ ] Multiple Categories
- [ ] National Battlefield
- [ ] National Historic ···
- [ ] National Historica···
- [ ] National Lakeshore
- [ ] National Memorial
- [ ] National Monument
- [x] National Park
- [ ] National Parkway
- [ ] National Preserve
- [ ] National Recreati···
- [ ] National River

Step 2:
Select a Park Service Unit

- Acadia National Park
- Arches National Park
- Badlands National Par
- Big Bend National Park
- Biscayne National Par
- Black Canyon Of The
- Bryce Canyon Nationa
- Canyonlands National
- Capitol Reef National
- Carlsbad Caverns Nati
- Channel Islands Natio
- Congaree National Pa
- Crater Lake National P




Because closed more info

Last Upda

Share | Download

See more by this author

© Headwaters Economics, 2011 Site Map | Contact | Press Room | Terms of Use | Photo Credits

ShareThis

HEADWATERS ECONOMICS | Land and Communities

# National Park Service Units:
## Economic Impacts of Visitation and Expenditures

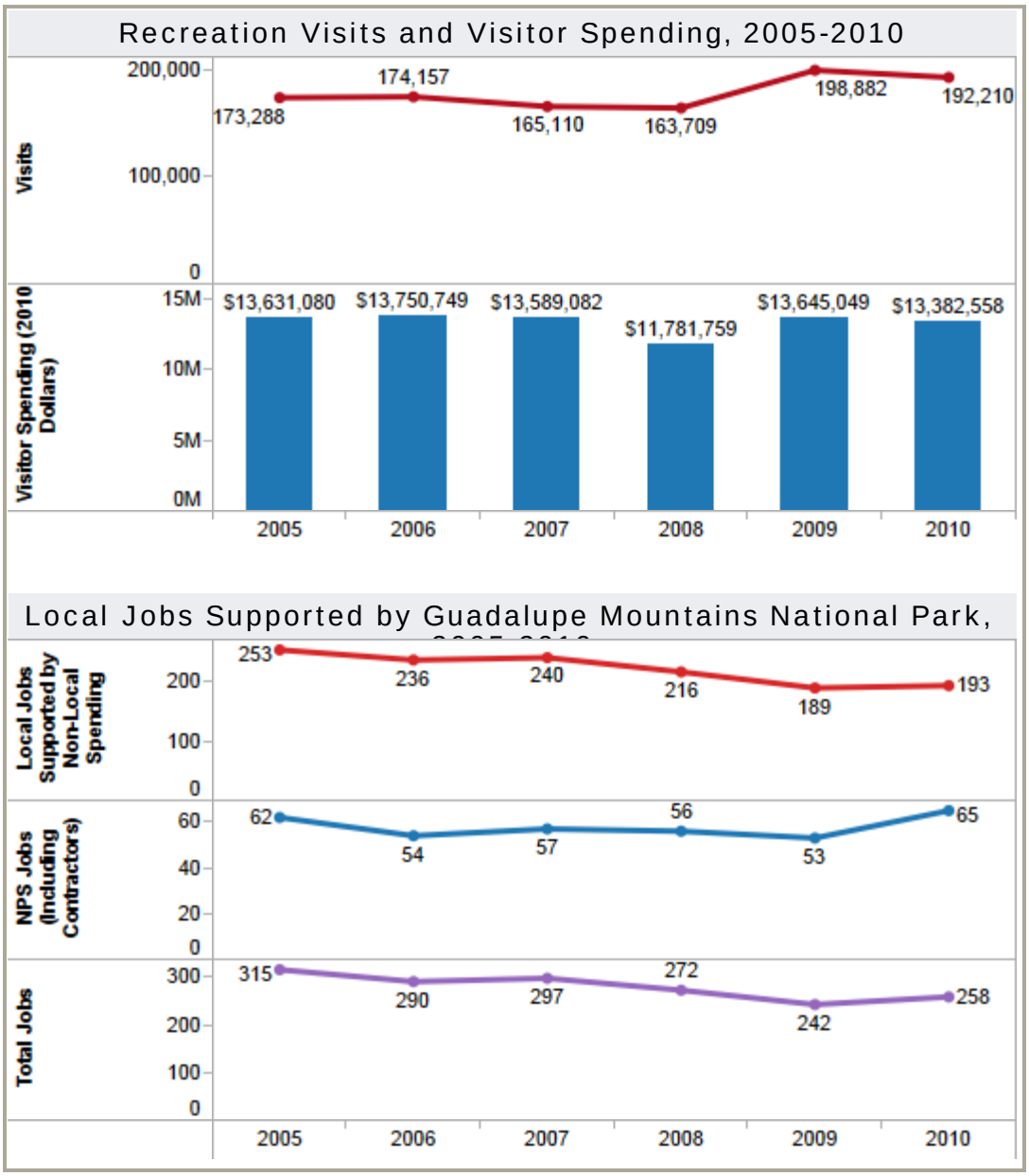
RELATED RESEARCH
The Value of Protected Lands
Socioeconomic Profiles

**Step 1:**
**Select One or More Par..**

- [ ] (All)
- [ ] Multiple Categories
- [ ] National Battlefield
- [ ] National Historic ···
- [ ] National Historica···
- [ ] National Lakeshore
- [ ] National Memorial
- [ ] National Monument
- [x] National Park
- [ ] National Parkway
- [ ] National Preserve
- [ ] National Recreati···
- [ ] National River

**Step 2:**
Select a Park Service Unit

- Acadia National Park
- Arches National Park
- Badlands National Par
- Big Bend National Par
- Biscayne National Par
- Black Canyon Of The
- Bryce Canyon Nationa
- Canyonlands National
- Capitol Reef National
- Carlsbad Caverns Nati
- Channel Islands Natio
- Congaree National Pa
- Crater Lake National P




Because closed more info

Last Upda

Share | Download

See more by this author

© Headwaters Economics, 2011 Site Map | Contact | Press Room | Terms of Use | Photo Credits

ShareThis

Abt Associates Inc. # 4800 Montgomery Lane #
Bethesda, MD 20814-5341 # www.abtassoc.com

Abt Associates Inc.

# Out of Sight: The Science and Economics of Visibility Impairment

# Executive Summary

# Out of Sight: The Science and Economics of Visibility Impairment

# Executive Summary

August 2000

*Prepared for*
Clean Air Task Force
Boston, MA

Project Manager:
Dr. L. Bruce Hill

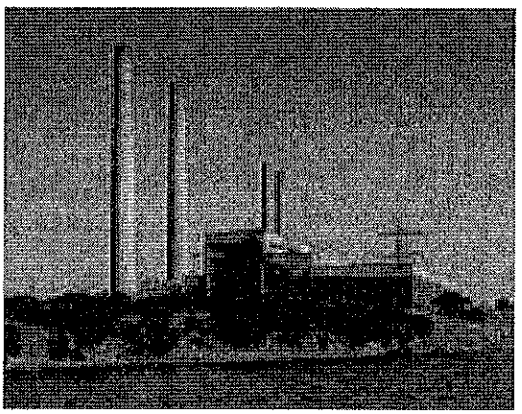
*Prepared by*
Abt Associates Inc.
4800 Montgomery Lane
Bethesda, MD 20814-5341
www.abtassoc.com

# EXECUTIVE SUMMARY

## Introduction

Visibility impairment is a basic form of air pollution, one that people can see and recognize without special instruments. It is also one of the scientifically best-understood byproducts of fossil fuel combustion. Despite this common knowledge, many people do not recognize the full costs of impaired visibility. Some people are not aware that visibility is impaired at all, incorrectly believing that the milky-white haze that blankets parts of the country is somehow a natural phenomenon associated with humidity, especially on hot summer days. In fact, visibility impairment is a major problem in the United States, with both aesthetic and economic consequences.

A variety of sources contribute to the air pollutant emissions that lead to visibility impairment, including power plants, motor vehicles, wildfires and industrial processes like smelting. The largest source in many areas is power plant emissions. This report is meant to give the educated reader a basic understanding of the nature and science of visibility impairment and to provide an overview of the economic costs of visibility impairment due to sources such as power plants.



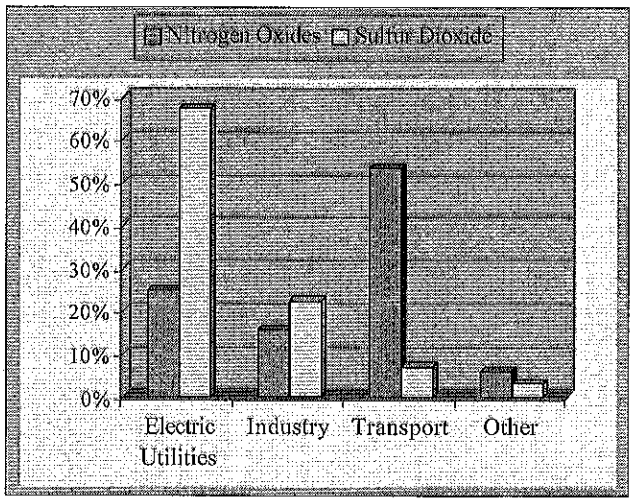
## Types And Causes of Visibility Impairment

Visibility impairment comes in a variety of forms: intrusive plumes from local smokestacks, a dirty low-lying cloud layer, a milky haze blanketing the view in all directions. Each type of visibility impairment occurs due to the nature and source of emissions and the prevailing meteorological conditions (Malm, 1999, p. 20). With stable atmospheric conditions and large, local emission sources, plumes and layered hazes are likely to occur. When atmospheric conditions are more turbulent and emissions arrive from distant sources, a regional haze can occur.

Plumes, layered haze, and regional haze differ from the clouds and fog that we might see on a rainy day, and instead are manmade impediments to visibility that federal, state, and local governments are actively trying to reduce. For regulatory purposes, the Environmental Protection Agency distinguishes between visibility impairment that is caused by one or a small group of sources, such as a the plume from a smoke stack, and visibility impairment that is caused by emissions over a wide geographic area. The distinction is made because emissions over a wide area are more diffuse and less easy to attribute to specific sources and, thus, more difficult to identify and control.

Most visibility impairment is caused by manmade air pollution, often carried by the wind hundreds of miles from where it originated. The large coal-fired electric utilities in the Ohio valley, some with stacks approaching 1000 feet tall, contribute to visibility problems over a wide area of the Eastern U.S. (Exhibit ES-1). Other contributors include motor vehicles, industrial fuel burning, manufacturing operations, and natural sources such as windblown dust, volatile organic compounds from plants, and soot from wildfires.

**Exhibit ES-1 National Emissions of Nitrogen Oxides and Sulfur Dioxide by Source in 1998**




These emission sources contribute "primary" particles, which are particulates emitted directly into the air, and "secondary" particles, which form from gases often carried many miles from their source. Both primary emissions and secondary formation of particles contribute to visibility impairment. Primary particles come from a variety of sources including diesel and wood combustion, and dust from industrial activities and natural sources. Secondary particles form in the atmosphere from gases emitted from power plants, cars, and a number of other sources, and are the most important in forming haze. In many areas, sulfate is the most important secondary particulate.

Some particles, like sulfates and nitrates become more effective during humid conditions as they absorb water and grow (Day et al., 2000, p. 716; Sisler, 1996, p. 4-7; U.S. EPA, 1996, p. 8-44). Sulfates and nitrates can more than triple in size as relative humidity increases, thus making visibility worse during periods of high humidity, such as the humid summer months in the East (National Research Council, 1993, p. 103). However, humidity alone does not cause visibility impairment. In the eastern U.S., sulfates account for the majority of visibility impairment. In the West, sulfates and organic carbon play about equal roles. Throughout the U.S., nitrates typically account for less than 10 percent of visibility impairment in most locations.

## Measuring Visibility Impairment

To conduct meaningful analyses of how visibility changes due to the presence of pollution in the atmosphere, there must be some standardized approach to measuring visual air quality. Visibility conditions are, therefore, commonly expressed in terms of three mathematically related metrics: visual range, light extinction, and deciviews.

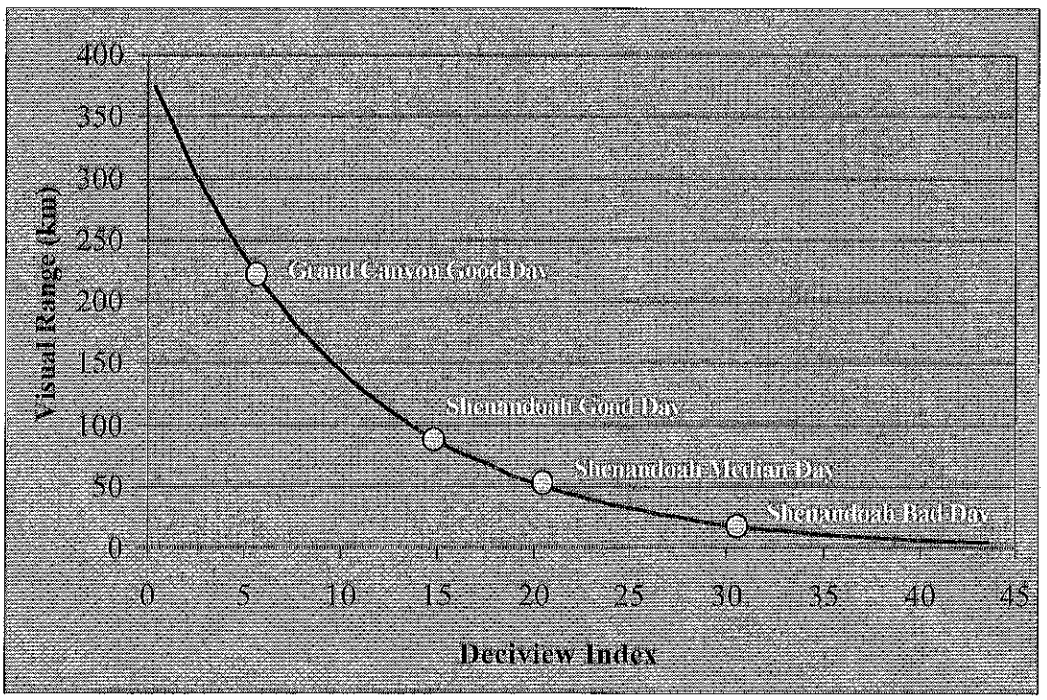
*Standard visual range* is the metric best known by the general public. It is the maximum distance at which one can identify a black object against the horizon, and is typically described in miles or kilometers. Higher visual range estimates mean better visibility.

*Light extinction* is a somewhat better alternative than visual range because it allows one to express the relative contribution of a PM constituent to overall visibility impairment. Light extinction is the sum of the light scattering and light absorption by particles and gases in the atmosphere. Higher extinction values

mean worse visibility. This is the inverse of visual range, where higher visual range estimates suggest better visibility (U.S. EPA, 1996, p. 8-56).

*Deciview index* provides a linear scale for perceived visual changes over the entire range of conditions. On a particle-free, pristine day, the deciview index has a value of zero. For each 10 percent increase in light-extinction, the deciview index goes up by one. So, higher deciview values mean worse visibility (Exhibit ES-2). Under many scenic conditions, a change of one deciview is considered to be just perceptible by the average person. However, it is important to understand that the same amount of pollution can have dramatically different effects on visibility depending on existing conditions. Most importantly, visibility in cleaner environments is more sensitive to increases in particle concentrations than visibility in more polluted areas.

**Exhibit ES-2 Inverse Relationship Between Visual Range and the Deciview Index**
(Source: NPS-CIRA, 2000).




## Trends in Visibility Impairment

Visibility conditions vary across the United States. Rural areas in the East generally have higher levels of impairment than most remote sites in the West. Visibility has generally worsened between the late 1940s and early 1980s, especially during the summer in the Southeast. This decline in visibility is closely matched with an increase in sulfur emissions (Malm, 1999, Figure 6.16b). Over the last decade visibility has marginally improved in some national parks, however there are clearly problem areas. In Exhibit ES-3, we present photographs to capture the range of visibility conditions at two well-known parks, Grand Canyon and Shenandoah.

In Exhibits ES-4 and ES-5, we present visibility measurements from 1988 to 1998. The National Park Service (NPS-CIRA, 2000) sorted each park's daily visibility measurements from low to high for each year, and placed them into three groups for analysis: "good" visibility days are the lowest 20 percent of daily measurements, "mid-range" days are the middle 40-60 percent, and "poor" visibility days are those days above the 80th percentile of the ordered data. We then plotted the annual average visibility measurement for each of these categories. To put the visibility category ranges observed at each park into perspective, we present actual photographs that represent the deciview levels for each national park for the good and poor visibility categories.

**Exhibit ES-3a Extreme Visibility Days at Grand Canyon National Park**
(Air Resource Specialists Inc., 1997, Img0010.pcd and Img0024.pcd)

**Excellent Visibility Day** (0 deciviews)

**Bad Visibility Day** (22 deciviews)

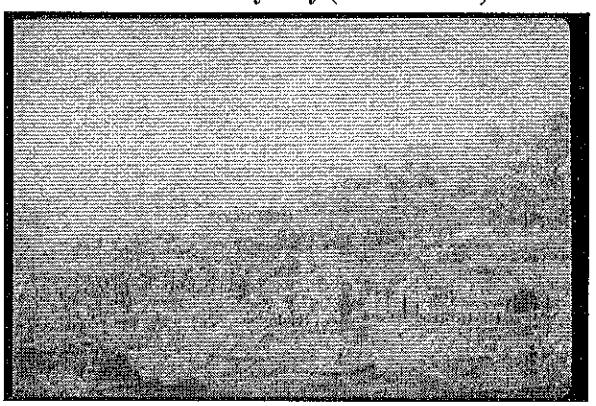


**Exhibit ES-3b Extreme Visibility Days at Shenandoah National Park**
(Air Resource Specialists Inc., 1999, Img0001.pcd and Img0011.pcd)

**Excellent Visibility Day** (4 deciviews)

**Bad Visibility Day** (44 deciviews)

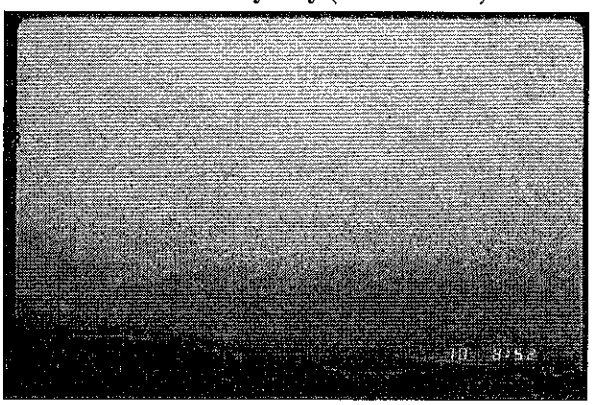
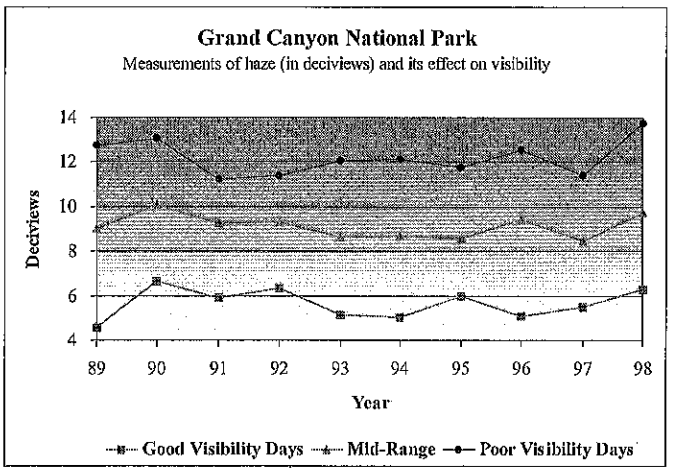
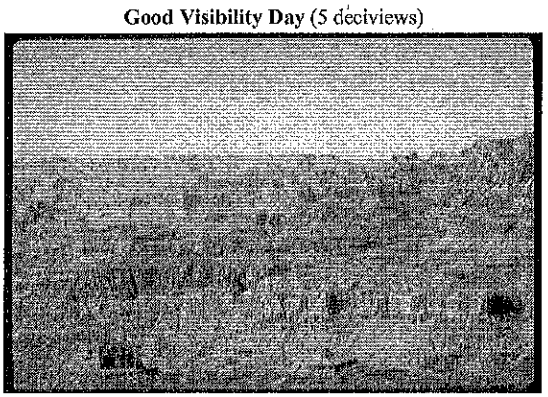


**Exhibit ES-4 Visibility Trends at Grand Canyon National Park, Arizona**
( Photos: Air Resource Specialists Inc., 1997, Img0015.pcd and Img0023.pcd; IMPROVE data: NPS-CIRA, 2000)




**Good Visibility Day** (5 deciviews)



**Poor Visibility Day** (13 deciviews)

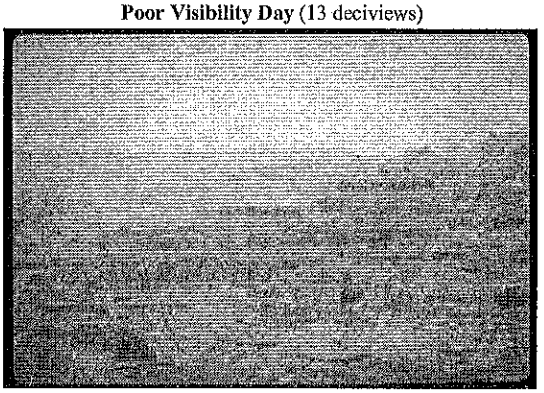
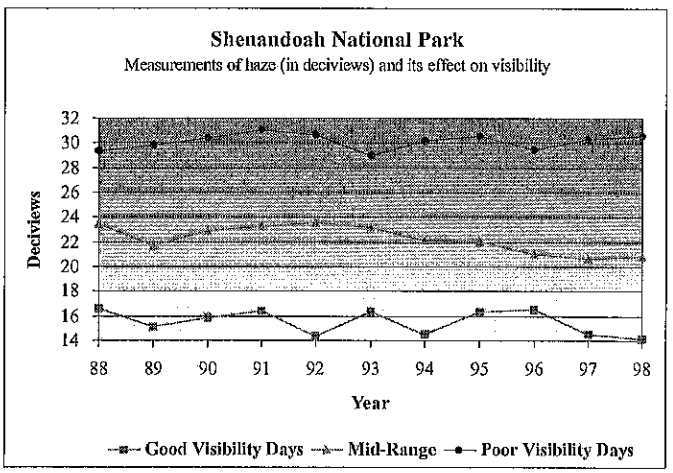
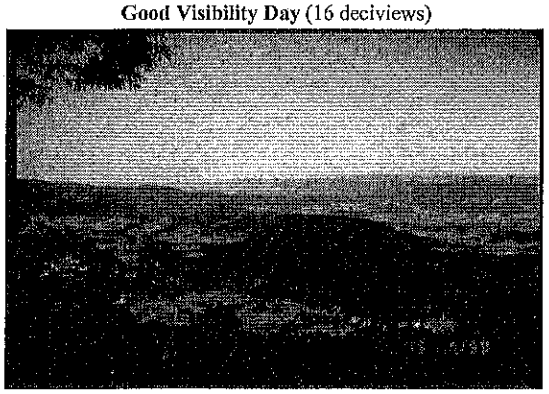


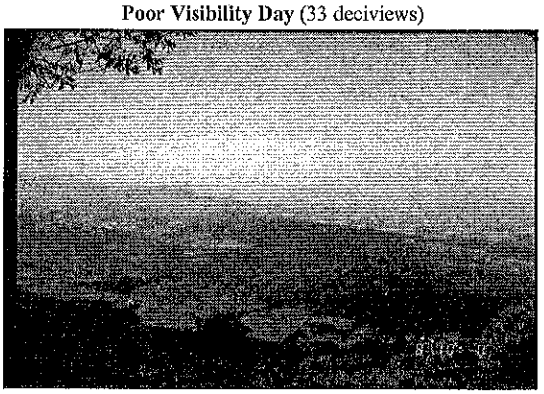
**Exhibit ES-5 Visibility Trends at Shenandoah National Park, Virginia**
( Photos: Air Resource Specialists Inc., 1999, Img0082.pcd and Img0085.pcd; IMPROVE data: NPS-CIRA, 2000)




**Good Visibility Day** (16 deciviews)



**Poor Visibility Day** (33 deciviews)



## The Economics of Visibility

Visibility is a commodity that cannot be bought or sold. This makes it difficult to measure what it is worth to people. Economists have taken on the challenge to devise ways of measuring the value of various types of environmental improvements, such as the improvements in visibility. One approach is to examine the economic impact of a reduction in park visitation, and an alternative approach is to directly estimate people's willingness to pay for improved visibility.

### *Visibility Impairment and Park Visitation*

One approach is to measure the affect poor air quality has on a person's decision to recreate. If, because of poor visibility, a person decides to shorten their visit to a particular park, or go to another recreation site altogether, the economic impacts will be felt in the way of lost revenue at the recreation site (park fees, lodging, concessions) and lost revenue in the communities close to the site (gas, food, lodging, concessions, additional tourist attractions). While visibility degradation is likely to affect most types of outdoor recreation to one degree or another, the impacts of impaired visibility are perhaps most pronounced at national parks.

It has consistently been shown that American vacationers believe that one of the leading attributes of a desirable travel destination is beautiful scenery and clean, clear air. In fact, the National Park Service (NPS, 1988) has conducted a number of studies that have examined the importance of clean air as a park feature. Park visitors perceive different degrees of visibility impairment, with hazy days detracting from their enjoyment of the park. Consistently among visitors' top priorities when visiting national parks are clear air and unobstructed views. When confronted with poor visibility at their destination, travelers shorten their stay or go elsewhere.

Tourism is a big industry in the U.S., supplying a significant number of jobs. The parks employ approximately 21,000 permanent and seasonal employees (NPS, 2000), and there are over 600 concessionaires in operation throughout the national park system providing visitors with lodging, transportation, food, shops and recreational services. In 1997, the NPS collected $122.2 million in recreation fee revenue, and concessions earned $650 million (U.S. Department of the Interior, 1988). One study, conducted by the Department of the Interior, measured the state and national economic impacts associated with all travel related expenditures (Peacock et al., 1998). The study estimated that travel related expenditures by visitors to National Parks generated an average of $14.55 billion (1996$) in annual output and approximately 210,000 jobs. Including all lands managed by the Department of the Interior, the study found annual economic impacts increased to $35 billion (1996$) and 500,000 jobs.

To measure the impact tourism has on communities adjacent to or near national parks, the NPS developed the Money Generation Model (MGM) to generate quick and inexpensive benefit estimates (NPS, 1998). The model estimates three types of economic benefits generated by park visitors: 1) income to local businesses; 2) increases in local area tax revenues; and 3) new jobs. We use MGM to demonstrate the potential impact on the local communities of seven popular destinations located through out the country: Acadia National Park, Big Bend National Park, Grand Canyon National Park, Great Smoky Mountains National Park, Indian Dunes National Lakeshore, Mt. Rainier National Park, and Shenandoah National Park.

We considered two scenarios for each park. In the first scenario, we assumed that visibility improves enough to increase visitation at the park by 10 percent. In the second scenario, we assumed that visibility improves enough to increase visitation at the park by 25 percent. For these changes in visitor activity at each of these parks, there are potentially large positive benefits to be gained (Exhibit ES-6). However, the benefits

are very rough estimates. The change in visitation is hypothetical, and the MGM is a simple model that provides only rough estimates of economic benefits.

**Exhibit ES-6a Sales Increase Near Park Due to an Increase in Park Visitation**

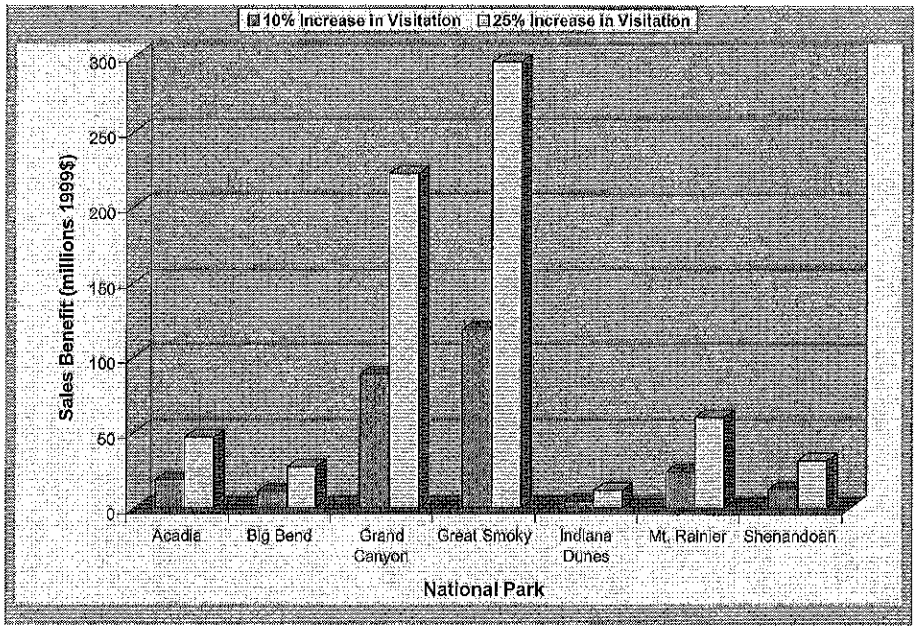



**Exhibit ES-6b Tax Revenue Increase Near Park Due to an Increase in Park Visitation**

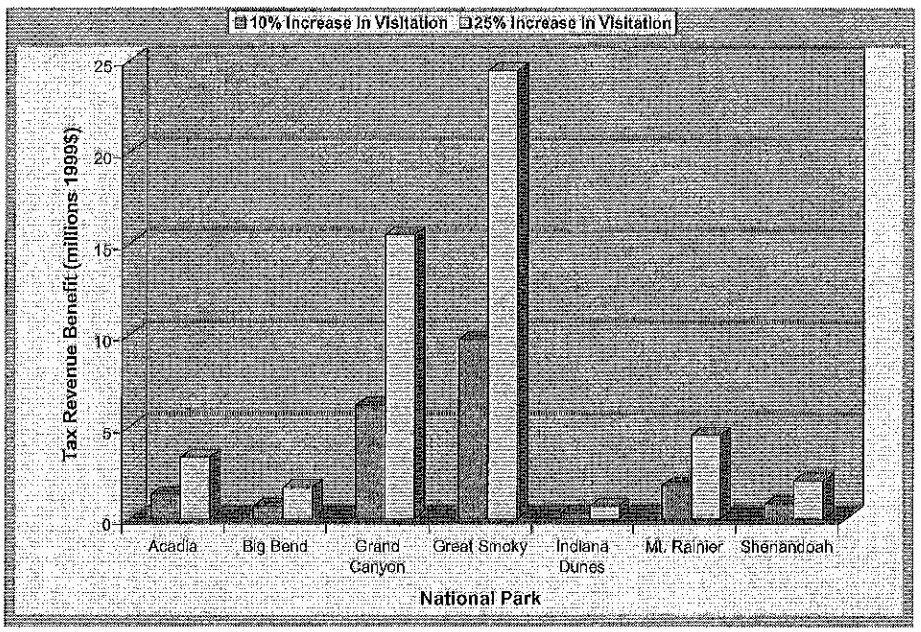
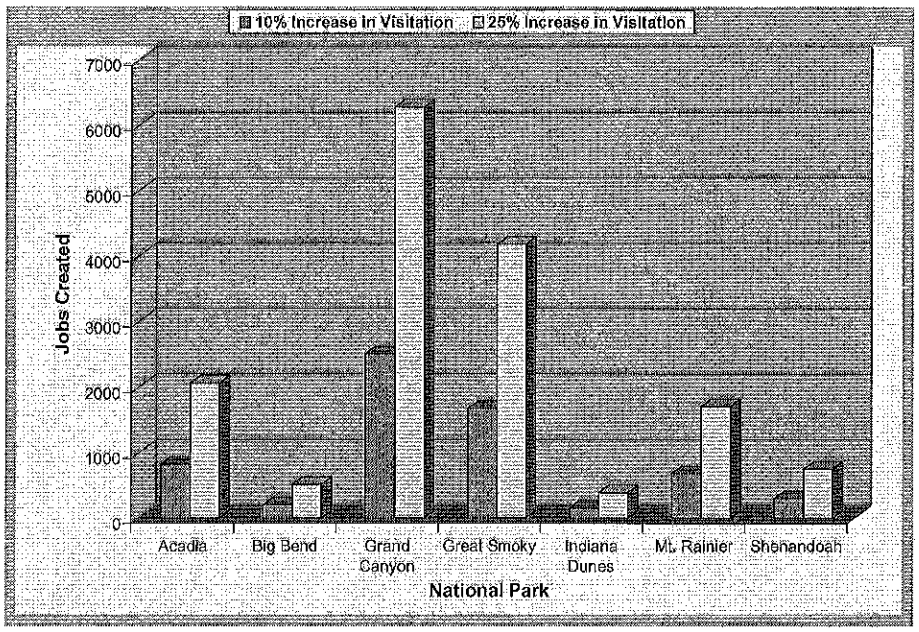


**Exhibit ES-6c Local Job Increase Near Park Due to an Increase in Park Visitation**




### *The Non-Market Value of Visibility*

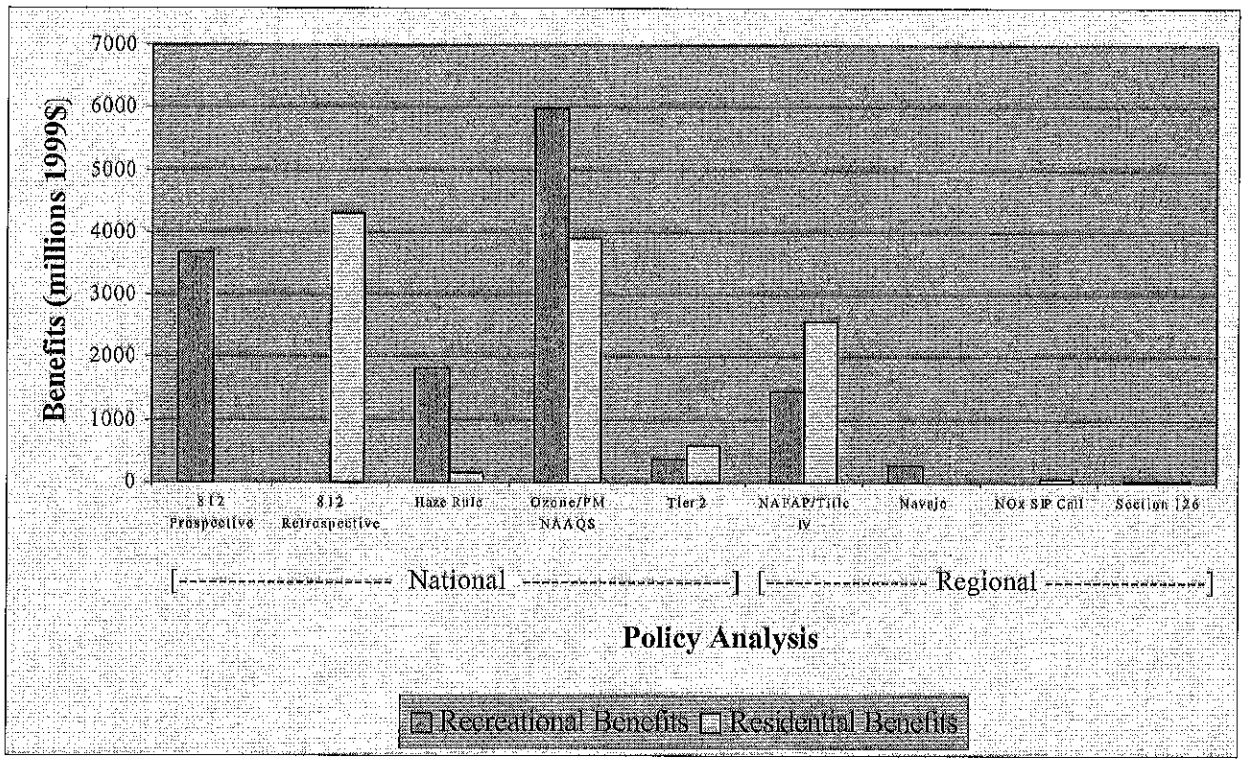
Another approach to value visibility is to survey people and ask their willingness to pay for better visibility. The most common method is known as the contingent valuation (CV) method. CV studies present people with a series of photographs of the same location at different visibility levels, and ask what they would be willing to pay each year to have visibility improve. While CV studies are still controversial because of their hypothetical nature, there has been much progress in designing studies to minimize the pitfalls and to maximize the likelihood that subjects clearly understand what it is they are being asked to value and that their answers will reflect their true willingness to pay.

CV studies have considered two broad measures of visibility benefits: "recreational" and "residential." Recreational visibility refers to people's willingness to pay for visibility improvement at national parks and wilderness areas, and residential visibility refers to people's willingness to pay for visibility improvement around their home. A number of researchers have looked at these visibility measures, and the results of their work are useful when estimating the impact of a regulatory action aimed at visibility improvement.

The value of visibility improvements due to a particular policy scenario has been a regular component of regulatory impact analyses for years. In each analysis, the policy-specific relationship between the amount of improvement in visibility and the average value households place on that improvement has been estimated, resulting in a range of benefit results. Exhibit ES-7 displays various recreational and residential visibility benefit totals that have been estimated for significant air quality policies over the last decade. While the results show a number of cases where there are substantial benefits, the results are not easily comparable since the geographic coverage and policy emphasis have varied from analysis to analysis. For example, the Section 812 Retrospective and Prospective Analyses measured visibility changes over the entire nation, while the Section 126 and $NO_x$ SIP Call Analyses only estimated visibility changes over a portion of the nation. In another

instance, the Haze Rule was specifically designed to improve visibility and has relatively large visibility benefits, while the Tier 2 Rule is not focused on visibility improvement and the benefits are relatively small.

**Exhibit ES-7 Visibility Benefits from Different Policy Analyses**




## Power Plant Emissions and Visibility Benefits

A series of legislative, regulatory and legal options are being considered to decrease sulfur dioxide ($SO_2$) and nitrogen oxide ($NO_x$) emissions from power plants in the United States. Although power plant emissions are currently regulated, and further reductions are required, power plant emissions still contribute to visibility impairment. In this hypothetical example, we estimate what visibility impairment would be in 2007 with the status quo policy, and what it would be if we were to shift to a policy that eliminates power plant emissions. To give a rough idea of the impact EGU emissions have on a National Park with significant visibility problems, we used WinHaze, a visual air quality model, to generate photographs of a poor visibility day for the status-quo and no-EGU scenarios in Great Smoky Mountains National Park (Exhibit ES-8).

We estimated the monetary value for two broad categories of visibility benefits: (1) changes in "residential" visibility – i.e., the visibility in and around the locations where people live; and (2) changes in "recreational" visibility at Class I areas – i.e., visibility at Class I national parks and wilderness areas.

The results of the analysis estimate that status-quo EGU emissions in the year 2007 will cost the United States $3.4 billion (1999$) in foregone residential visibility benefits and $4.3 billion (1999$) in foregone recreational visibility benefits (Exhibits ES-9 and ES-10). In total, EGU emissions will cost the United States $7.7 billion in foregone total visibility benefits. Of course, the full extent of these foregone benefits will never be realized because EGU emissions will never be completely eliminated. These foregone visibility benefit totals, however, reflect the potential for substantial visibility-related benefits if EGUs were to reduce emissions beyond current levels.

**Exhibit ES-8 WinHaze Split-Image of a Poor Visibility Day at Great Smoky Mountains National Park for the Status Quo and No-EGU Scenarios**

Status Quo (visual range=20km) No-EGU (visual range=43km)

## Exhibit ES-9 State-Level Residential Visibility Benefits

| State | Monetary Benefits (1999$) | State | Monetary Benefits (1999$) |
|---|---|---|---|
| Alabama | $74 | Nebraska | $149 |
| Arizona | $35 | Nevada | $5 |
| Arkansas | $8 | New Hampshire | $19 |
| California | $61 | New Jersey | $25 |
| Colorado | $14 | New Mexico | $139 |
| Connecticut | $56 | New York | $4 |
| Delaware | $9 | North Carolina | $4 |
| District of Columbia | $17 | North Dakota | $270 |
| Florida | $208 | Ohio | $183 |
| Georgia | $123 | Oklahoma | $33 |
| Idaho | $46 | Oregon | $8 |
| Illinois | $3 | Pennsylvania | $230 |
| Indiana | $190 | Rhode Island | $16 |
| Iowa | $114 | South Carolina | $66 |
| Kansas | $28 | South Dakota | $8 |
| Kentucky | $71 | Tennessee | $95 |
| Louisiana | $37 | Texas | $170 |
| Maine | $93 | Utah | $6 |
| Maryland | $124 | Vermont | $132 |
| Massachusetts | $17 | Virginia | $10 |
| Michigan | $167 | Washington | $27 |
| Minnesota | $47 | West Virginia | $81 |
| Mississippi | $93 | Wisconsin | $29 |
| Missouri | $38 | Wyoming | $2 |
| Montana | $3 | **TOTAL** | $3,385 |

**Exhibit ES-10 State-Level Recreational Visibility Benefits**

| State | Benefits (millions 1999$) | State | Benefits (millions 1999$) |
|---|---|---|---|
| Alabama | $2.1 | North Dakota | $16.8 |
| Arkansas | $1.6 | New Hampshire | $6.0 |
| Arizona | $293.3 | New Mexico | $20.6 |
| California | $218.7 | Nevada | $0.1 |
| Colorado | $152.6 | Oregon | $10.0 |
| Florida | $58.6 | South Dakota | $95.0 |
| Idaho | $5.8 | Tennessee | $1,839.2 |
| Kentucky | $147.8 | Texas | $44.4 |
| Maine | $327.8 | Utah | $142.3 |
| Michigan | $20.6 | Virginia | $128.3 |
| Minnesota | $97.2 | Vermont | $0.6 |
| Missouri | $2.3 | Washington | $263.8 |
| Montana | $69.4 | West Virginia | $4.4 |
| North Carolina | $6.8 | Wyoming | $277.7 |

## References


Air Resource Specialists Inc. 1997. Grand Canyon National Park Arizona: IMPROVE Monitoring Network Permanent Photographic Archive 1983-1996, Slide Spectrum. September. Prepared for the IMPROVE program, NPS Contract #CX-1270-96-006. Fort Collins, CO.

Air Resource Specialists Inc. 1999. Shenandoah National Park Virginia: IMPROVE Monitoring Network Permanent Photographic Archive 1991-1995, Slide Spectrum. Prepared for the IMPROVE program, NPS Contract #CX-1270-96-006. Fort Collins, CO.

Day, D.E., W.C. Malm and S.M. Kreidenweis. 2000. Aerosol light scattering measurements as a function of relative humidity. J Air Waste Manag Assoc. Vol. 50(5): 710-716.

Malm, W.C. 1999. Introduction to Visibility. Cooperative Institute for Research in the Atmosphere (CIRA). Fort Collins, CO. Cooperative Agreement. May.

National Park Service. 1988. Air Quality in the National Parks. National Park Service, Air Quality Division. Denver, Colorado. Natural Resources Programs, Natural Resources Report 88-1.

National Park Service. 1998. The Money Generation Model. Executable dated March 4. National Park Service, Public Use Statistics Office. http://www.nps.gov/planning/mgm.

National Park Service. 2000. Recreation Visits 1951-1998. May. National Park Service, Public Use Statistics Office. http://www2.nature.nps.gov/stats/.

National Park Service (NPS) and the Cooperative Institute for Research in the Atmosphere (CIRA). 2000. IMPROVE Data Available at FTP Site. Downloaded May 28. National Park Service, Air Resources Division - Cooperative Institute for Research in the Atmosphere, Colorado State University. Fort Collins, CO. http://alta_vista.cira.colostate.edu/.

National Research Council. 1993. Protecting visibility in national parks and wilderness areas. National Academy Press: Washington, DC.

Peacock, B., C. Killingsworth and B. Simon. 1998. State and National Economic Impacts Associated with Travel Related Expenditures by Recreational Visitors to Lands Managed by the U.S. Department of the Interior. U.S. Department of the Interior. January 16.

Sisler, J.F. 1996. Spatial and Seasonal Patterns and Long Term Variability of the Composition of the Haze in the United States: An Analysis of Data from the IMPROVE Network. Colorado State University, Cooperative Institute for Research in the Atmosphere. Fort Collins, CO. July.

U.S. Department of the Interior. 1988. Recreational Fee Demonstration Program, Volume I – Overview and Summary. Progress Report to Congress. January 31.

U.S. EPA. 1996. Air Quality Criteria for Particulate Matter. Volume II. U.S. EPA, Office of Research and Development. Washington, DC. EPA-/600/P-95/001bF. April.

Abt Associates Inc.

Abt Associates Inc. # 4800 Montgomery Lane # Bethesda, MD 20814-5341
www.abtassoc.com # ph: 301-913-0500 # fax: 301-652-3618

# EXHIBIT 12

Acid Rain Home
What is Acid Rain?
Where You Live
Measuring Acid Rain
Effects of Acid Rain
Reducing Acid Rain
Educational Resources
Related Links
Glossary
For Students

# Effects of Acid Rain

Acid rain causes acidification of lakes and streams and contributes to the damage of trees at high elevations (for example, red spruce trees above 2,000 feet) and many sensitive forest soils. In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage. Prior to falling to the earth, sulfur dioxide ($SO_2$) and nitrogen oxide ($NO_x$) gases and their particulate matter derivatives —sulfates and nitrates—contribute to visibility degradation and harm public health.

The links below provide more detailed information on each of these effects:

- Surface waters (lakes and streams) and aquatic animals
- Forests
- Automotive coatings
- Materials
- Visibility
- Human health



**This document will now print as it appears on screen when you use the File » Print command.**
Use View » Refresh to return to original state.

**This document will now print as it appears on screen when you use the File » Print command.**
Use View » Refresh to return to original state.

# EXHIBIT 13

Journal of Environmental Management 103 (2012) 165–171

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

# Nitrogen critical loads for alpine vegetation and soils in Rocky Mountain National Park

William D. Bowman [a,b,*], John Murgel [a,b,1], Tamara Blett [c], Ellen Porter [c]

[a] Mountain Research Station, Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO 80309, USA
[b] Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, CO 80309, USA
[c] National Park Service, Air Resources Division, Lakewood, CO 80225, USA

ARTICLE INFO

*Article history:*
Received 23 June 2011
Received in revised form
27 December 2011
Accepted 2 March 2012
Available online 18 April 2012

*Keywords:*
Acidification
Alpine tundra
Base cations
Critical loads
Diversity response
Eutrophication
Mountain ecosystems
Nitrogen deposition
Rocky Mountain National Park

ABSTRACT

We evaluated the ecological thresholds associated with vegetation and soil responses to nitrogen (N) deposition, by adding $NH_4NO_3$ in solution at rates of 5, 10 and 30 kg N $ha^{-1}$ $yr^{-1}$ to plots in a species rich dry meadow alpine community in Rocky Mountain National Park receiving ambient N deposition of 4 kg N $ha^{-1}$ $yr^{-1}$. To determine the levels of N input that elicited changes, we measured plant species composition annually, and performed one-time measurements of aboveground biomass and N concentrations, soil solution and resin bag inorganic N, soil pH, and soil extractable cations after 3 years of N additions. Our goal was to use these dose–response relationships to provide N critical loads for vegetation and soils for the alpine in Rocky Mountain National Park. Species richness and diversity did not change in response to the treatments, but one indicator species, *Carex rupestris* increased in cover from 34 to 125% in response to the treatments. Using the rate of change in cover for *C. rupestris* in the treatment and the ambient plots, and assuming the change in cover was due solely to N deposition, we estimated a N critical load for vegetation at 3 kg N $ha^{-1}$ $yr^{-1}$. Inorganic N concentrations in soil solution increased above ambient levels at input rates between 9 kg N $ha^{-1}$ $yr^{-1}$ (resin bags) and 14 kg N $ha^{-1}$ $yr^{-1}$ (lysimeters), indicating biotic and abiotic sinks for N deposition are exhausted at these levels. No changes in soil pH or extractable cations occurred in the treatment plots, indicating acidification had not occurred after 3 years. We conclude that N critical loads under 10 kg $ha^{-1}$ $yr^{-1}$ are needed to prevent future acidification of soils and surface waters, and recommend N critical loads for vegetation at 3 kg N $ha^{-1}$ $yr^{-1}$ as important for protecting natural plant communities and ecosystem services in Rocky Mountain National Park.
© 2012 Elsevier Ltd. All rights reserved.

## 1. Introduction

Emissions of reactive nitrogen (N) by agricultural development and fossil fuel combustion have increased the deposition of N more than threefold over the past 160 years (Galloway et al., 2008). The environmental impact of these N inputs on terrestrial ecosystems varies according to vegetation type, chemistry of the soil parent material, and the rate and accumulated input of N deposition (Aber et al., 1998; Clark and Tilman, 2008). Enhanced net primary production (eutrophication) may occur where N remains the limiting resource for plant growth (e.g. Binkley and Högberg, 1997; Thomas et al., 2010). Greater N availability often results in losses of plant diversity (Gough et al., 2000; Stevens et al., 2004; Suding et al., 2005; Bobbink et al., 2010) and greater establishment of invasive species (Yoshida and Allen, 2004; Rao and Allen, 2010). Once plants, microorganisms, and soils cease to take up N entering the system from deposition, leaching of nutrient base cations, increases in soluble aluminum, and soil acidification can occur, eventually leading to decreases in plant growth and continued losses in diversity (Stevens et al., 2004; Bowman et al., 2008).

The environmental impacts of N deposition on terrestrial systems have been recorded primarily for industrialized regions such as northern and central Europe and the eastern United States (Bobbink et al., 1998; Driscoll et al., 2001). However, symptoms of ecological changes due to N deposition are showing up in more remote regions, including national parks and wilderness areas in the Rocky Mountains and Sierra Nevada in the U.S. (Burns, 2003; Fenn et al., 2003; Geiser and Neitlich, 2007). These symptoms include elevated surface water nitrate concentrations and greater abundances of nitrophilic lichen and diatom species in areas with elevated N deposition. Mountain ecosystems are especially sensitive to inputs of N deposition due to thin soils and low rates of net

* Corresponding author. Mountain Research Station, Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO 80309, USA. Tel.: +1 303 492 2557; fax: +1 303 492 8699.
*E-mail address:* william.bowman@colorado.edu (W.D. Bowman).
[1] Present address: Department of Horticulture and Landscape Architecture, Colorado State University, Fort Collins, CO 80523, USA.

0301-4797/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2012.03.002

primary production, limiting the uptake and stabilization of reactive N (Williams and Tonnessen, 2000; Weathers et al., 2006).

The ecological changes in ecosystems subjected to elevated N deposition, from initial eutrophication and loss of diversity, to decreased productivity and acidification, may occur as thresholds of N inputs are reached and exceeded (Aber et al., 1998; Groffman et al., 2006). The reversibility from one stage of impact to another is uncertain, as biological and geochemical feedbacks may create substantial inertia. For example, changes in plant diversity due to N deposition may enhance rates of N cycling of existing soil organic matter, with higher rates of net mineralization and nitrification increasing pools of soil inorganic N (Bowman and Steltzer, 1998). Depletion of base cations may shift the soil buffering system toward an aluminum dominated system (Chadwick and Chorover, 2001). Thus the best approach to mitigating environmental impacts of N deposition is to recognize the initial ecological responses and associated deposition rates, and manage air pollutant emissions to minimize further ecosystem changes.

The critical load concept uses sensitive ecological indicators to help minimize detrimental environmental impacts (Burns et al., 2008). A critical load is defined as the level of input of one or more pollutants below which there are no significant negative impacts on sensitive environmental elements (Nilsson and Grennfelt, 1988; Porter et al., 2005). Critical loads for nitrogen deposition have been established using modeling and empirical approaches. The latter often uses observations of ecological changes across gradients of N deposition, as well as experimental manipulations. The occasional use of high levels of N inputs in experiments to determine thresholds of ecological response, and relatively high ambient levels of N deposition, can result in somewhat arbitrary determinations of critical loads.

The goal of the research described here was to determine the responses of vegetation and soils in a sensitive alpine community in Rocky Mountain National Park to a gradient of relatively low-level N applications (5–30 kg N $ha^{-1}$ $yr^{-1}$) to help determine the critical load for N. The Clean Air Act Amendments of 1977 designated Rocky Mountain National Park as a Class I air quality area, and Congress directed park managers to preserve air pollution-sensitive resources unimpaired for future generations (NPS ARD, 2002). N critical loads for vegetation and soils can be used to manage the park's resources more effectively and to ensure that sensitive resources are protected from air pollution now and in the future.

## 2. Materials and methods

### 2.1. Study site

The research was performed in a dry meadow community approximately 2 km east of Chapin Pass in the Mummy Range, Rocky Mountain National Park (40° 26′ 03.25″ N, 105° 43′ 3.45″ W). The site was located on a west-facing slope at 3560 m elevation above sea level. An alpine dry meadow site was selected for this work as 1) it is one of the most sensitive communities due to inherently low rates of nutrient cycling and associated plant adaptations to low nutrient supply (Bowman and Bilbrough, 2001), 2) plant species density is high (~30 species/$m^2$), increasing the probability of finding indicator species, and 3) these communities make up a significant part of the alpine landscape (~40%, Komárková, 1979). Dry meadows are dominated by the sedge *Kobresia myosuroides*, with additional sedges, primarily *Carex rupestris*, grasses, and forbs making up the remaining cover (Komárková, 1979). Soils are cryumbrepts derived from metamorphic granitoid parent material. The C:N ratios for mineral soil (0–10 cm depth) at the site are 13.3 ± 0.1 (mean ± s.e.m., $n = 20$). Climate at the site is characterized by long cold winters and a short growing season of 10–12 weeks.

Total ambient inorganic N deposition at the site is 4 kg N $ha^{-1}$ $yr^{-1}$ (Baron, 2006), estimated from wet deposition measurements at a nearby National Atmospheric Deposition Program sampler (Loch Vale, 3159 m elevation, 17 km south on the same side of the Continental divide) and dry deposition estimates from a lower elevation CASTNet Dry Deposition monitor (Beaver Meadows, 2743 m elevation, 16 km east southeast, on the same side of the Continental divide). Wet deposition accounts for 75% and dry deposition accounts for 25% of the total N deposition. Deposition of reactive N consists of 41% $NH_4^+$–N and 59% $NO_3^-$–N (EPA CASTNET, http://epa.gov/castnet). Given the projected population growth for the Front Range cities in the Denver megalopolis and the rate of agricultural development, N deposition is expected to increase steadily in Rocky Mountain National Park over the next several decades, with rates approaching 1.5 times current rates by 2030 (Fenn et al., 2003; Dentener et al., 2006).

### 2.2. Experimental procedures

Experimental N additions consisted of ambient N deposition (4 kg N $ha^{-1}$ $yr^{-1}$), and addition of 5, 10, and 30 kg N $ha^{-1}$ $yr^{-1}$ added to 5 replicate 1 m × 1.5 m plots. These levels represent 1.25×, 2.5×, and 7.5× ambient deposition rates. This range of N additions allowed estimation of response curves of soils and vegetation to increasing N deposition, facilitating a quantitative estimation of N critical loads (Bowman et al., 2006). Nitrogen was added as $NH_4NO_3$ in solution, sprayed onto the plots three times during the growing season. The maximum solution concentrations added to the plots ranged from 4.5 mmol N in the +5 kg N $ha^{-1}$ $yr^{-1}$ treatment to 26.8 mmol N in the +30 kg N $ha^{-1}$ $yr^{-1}$ treatment, which are well below levels that cause toxicity to plants. Control plots received an equivalent amount of water (4 L $plot^{-1}$ $application^{-1}$). The amount of water added to plots represented a 5% increase in mean summer precipitation, well within the range of interannual variation, and therefore not a substantial treatment effect. Half of the N addition was added in the first application in early June, to better reflect that approximately half of annual input of N occurs as a pulse during snowmelt (Bowman, 1992). No overland flow of the treatment solutions was observed. The plots were arranged in 5 blocks, with one replicate plot of each treatment in each of the blocks (total of 20 plots). Treatment plots were separated by a minimum of a 2 m buffer zone. The uphill 1 m × 1 m portion of each plot was used for measurement of vegetation cover. The downhill 0.5 m × 1 m portion was used for soil sampling. The plots were established in 2006 and received the N additions each year for four years.

To evaluate the effect of the N treatments on the vegetation, cover of individual vascular plant species, bare ground, rocks, scat (proxy for herbivory), and litter were estimated using the point-intercept method, with 100 points in each plot. Cover estimates were made annually during the growing season when all species were present and identifiable, in mid- to late-July. The effect of the N treatments on aboveground net primary production (NPP) was estimated using a clip harvest of all aboveground biomass collected in late-July 2008. Three 0.2 m × 0.2 m subplots were used for biomass harvesting. The biomass was field sorted into three groups: *Kobresia* (dominant species), other graminoids (grasses and sedges), and forbs. The harvested biomass was dried to a constant mass by placing in a drying oven for 48 h at 70 °C, and then weighed to the nearest mg. The influence of N treatment on tissue N concentrations was evaluated by grinding the dried biomass with a mortar and pestle, and then analyzing the ground tissue using a CHN Analyzer. The uptake of N by the aboveground tissues was evaluated by multiplying the tissue N concentrations by the biomass accumulation measured by the clip harvests.

Soil responses to N inputs included soil solution inorganic N, resin bag N, soil pH, and extractable cations. Soil solution and resin bag inorganic N were collected in the third year of the experiment

(2008). Soil water was collected using vacutainers attached to the microlysimeters (Rhizon soil moisture samplers, Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands), which was analyzed for inorganic N using a Lachat QuikChem 8000 Spectophotometric Flow Injection Analyzer and a Dionex DX 500 System IonPac AS11 Ion Chromatograph (Sunnyvale, California, USA). Inorganic N leaching below the rooting zone was estimated using ion exchange resin bags, constructed of plastic cylinders (4.9 $cm^2$ and 2.5 cm height) filled with mixed-bed ion exchange resins (J.T. Baker, IONAC NM-60 H/OH; Phillipsburg, New Jersey, USA) and covered with nylon mesh. Two resin bags per plot were inserted into the edge of an excavated hole below a column of undisturbed soil at a 15 cm depth, which is below the zone of maximum rooting density for dry meadow plants (10 cm, Webber and May, 1977). The resin bags were deployed in June 2008 and removed at snowmelt in June 2009. After retrieval the bags were opened, and the resin extracted using 2 N KCl. The extractant was analyzed for inorganic N as described above.

Soil pH and extractable cations were measured in the first year of the experiment (2006) and again in the third year of the experiment (2008). Two soil cores (A horizon, 1.5 cm diameter, 10 cm depth) were collected from each plot, sieved to 2 mm, and then composited for each plot and air dried. Soil pH was measured using a Beckman 340 pH probe on a 1:2 soil: distilled water paste determined after 30 min of shaking. Another subset of the soil was extracted with 0.1 M BaCl, and the extractant was analyzed for $Ca^{2+}$, $K^+$, $Mg^{2+}$, $Na^+$, $Mn^{2+}$, $Al^{3+}$, $Fe^{3+}$ using an ARL 3410 Inductively Coupled Plasma Emission Spectrophotometer (ICP-AES; Thermo Electron, Waltham, MA, USA).

### 2.3. Data analyses

Changes in the cover of individual plant species in response to increases in N inputs were evaluated using repeated measures general linear model MANOVA, with block as a categorical covariate in the model to account for potential microsite influences. Significant effects of the N treatments on cover were evaluated using the year × treatment interaction terms (Wilks lambda), which indicate whether temporal changes in the cover of species differed among the treatments. The effect of the N treatments on aboveground NPP, tissue N concentrations and N uptake, soil solution and resin bag inorganic N, soil pH, and extractable base cations was evaluated using a one-way general linear model ANOVA, with block as a categorical covariate when significant. All data sets were evaluated prior to ANOVA testing to assure they met the assumptions of the tests. Arcsine transformations were needed for the resin bag and soil solution inorganic N data to meet the assumptions of the tests.

## 3. Results

### 3.1. Effect of N treatments on plant species cover

A total of 43 vascular plant species occurred within the plots (9–24 species $m^{-2}$ plot), with the sedges *K. myosuroides* and *C. rupestris* making up the greatest amount of cover (average of 41% and 26% cover, respectively). Neither species richness nor the Shannon–Wiener diversity index (H′), which incorporates both the richness and evenness of species, changed with treatment or time. The only species that exhibited a significant response to the N treatments was *C. rupestris*, which increased in a dose dependent manner (significant treatment × time interaction in repeated measures ANOVA, $F = 4.59$, Wilks lambda $P = 0.02$, Fig. 1a). The mean cover of *C. rupestris* increased by 34%, 69%, 86%, and 125% over the four year period in the 0 (ambient), 5, 10, and 30 kg N $ha^{-1}$ $yr^{-1}$ treatments, respectively.

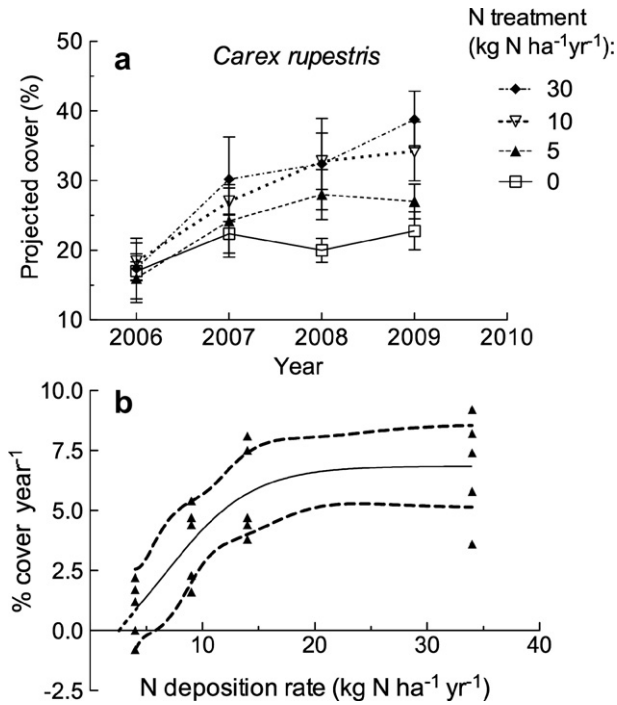



**Fig. 1.** Cover (a, symbols are means ± s.e.m., $n = 5$) and rate of change in cover (b, each plot represented by a triangle) for *Carex rupestris* in an alpine dry meadow in Rocky Mountain National Park subjected to ambient deposition (control), and additions of 5, 10, and 30 kg N $ha^{-1}$ $yr^{-1}$. The data were fit with a sigmoidal dose response curve (solid line, $r^2 = 0.67$, 95% confidence interval shown by the dotted lines). The extrapolation of the line to the *x*-axis in b provides an estimate of the threshold of N input at which significant increases in cover of *C. rupestris* occurs due to N deposition.

### 3.2. Estimate of N critical load for vegetation change

The N critical load for changes in vegetation was estimated as the N input level below which no increase in *C. rupestris* cover would occur, as indicated here by the threshold at which cover increased. We assumed that no other factor contributed to the observed change in *C. rupestris* cover at the research site; e.g. climate change in this region has been minimal or non-significant (Pepin and Losleben, 2002; Clow, 2010). An analysis of growing season temperatures at the nearest site for which long-term data are available (Loch Vale) indicated the mean monthly temperatures for June, July, and August during 2006–2009 (June: 9.7 ± 0.4, July: 13.4 ± 0.2, August: 11.9 ± 0.3) were not different from the 1983–2005 averages (June: 9.5 ± 0.1, July: 13.2 ± 0.1, August: 12.1 ± 0.1). Furthermore past experiments at Niwot Ridge have determined that N, but not P or water, limits the growth of *C. rupestris* (Bowman et al., 1995). We estimated the N input threshold for changes in *C. rupestris* cover in all plots using linear regression analyses of the rate of change in projected cover for each of the 20 plots. The response function for the change in *C. rupestris* cover per year versus the N input rate (including ambient deposition) was estimated using a sigmoidal dose response curve (Fig. 1b), with the *x*-intercept providing the N critical load for vegetation. This approach yielded a N critical load for vegetation change of 3 kg N $ha^{-1}$ $yr^{-1}$.

### 3.3. Changes in aboveground biomass and tissue N concentrations and N content

The total aboveground biomass did not change significantly in response to the N treatments after 3 years (Fig. 2a). However, there

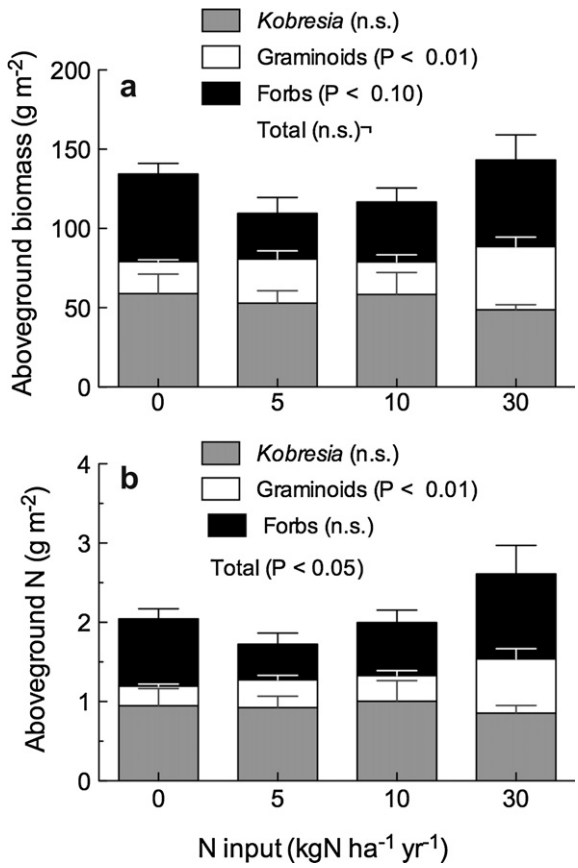



**Fig. 2.** Biomass (a) and N content (b) of aboveground vegetation in an alpine dry meadow in Rocky Mountain National Park subjected to 3 years of ambient deposition (control), and additions of 5, 10, and 30 kg N ha$^{-1}$ yr$^{-1}$. Plant tissues were separated into the dominant species (*Kobresia*), all other sedges and grasses (graminoids), and forbs. Bars are means ± s.e.m. ($n = 5$).

was a significant increase in biomass of graminoids (which includes *C. rupestris*) ($F = 13.6$, $P < 0.01$). There was a significant influence of microsite on total biomass (block effect, $F = 9.1$, $P = 0.001$), but not on the other components of biomass.

Nitrogen concentrations in aboveground tissues increased significantly with increasing N inputs for the graminoids ($F = 13.4$, $P < 0.01$) and forbs ($F = 10.9$, $P < 0.01$), but not for *Kobresia* ($F = 0.54$, $P = 0.48$) (Table 1). Concentrations increased by an average of 40% in graminoids and 27% in forbs between the 0 and 30 kg N ha$^{-1}$ yr$^{-1}$ treatments.

The total pool of N in aboveground biomass increased with increasing N input as a result of both increases in tissue N concentrations and biomass in the graminoids ($F = 27.1$, $P < 0.001$ for graminoids N content, $F = 5.2$, $P = 0.04$ for total biomass N content). Nitrogen content in aboveground biomass increased 29% between the 0 and 30 kg N ha$^{-1}$ yr$^{-1}$ treatments (Fig. 2b).

### 3.4. Effects of N treatments on soil inorganic N, cations and pH

Soil solution $NO_3^-$–N and $NH_4^+$–N both increased significantly with the N treatments (Fig. 3a, $F = 18.0$, $P < 0.001$ for $NO_3^-$–N; $F = 17.4$, $P < 0.001$ for $NH_4^+$–N). Significant deviation from the control soil solution concentrations of $NO_3^-$–N occurred between 9 and 14 kg N ha$^{-1}$ yr$^{-1}$, based on the 95% confidence interval of the regression analysis.

Resin bag $NO_3^-$–N concentrations also increased significantly with the N treatments (Fig. 3b, $F = 18.0$, $P < 0.001$), and there was a trend of an increase for $NH_4^+$–N ($F = 2.9$, $P = 0.09$). Significant deviation from the control (0) resin bag concentrations of $NO_3^-$–N occurred above 9 kg N ha$^{-1}$ yr$^{-1}$, based on the 95% confidence interval of the regression analysis.

**Table 1**
Tissue N concentrations for aboveground biomass collected in plots treated with 0 (control), 5, 10, and 30 kg N ha$^{-1}$ yr$^{-1}$ in an alpine dry meadow, Rocky Mountain National Park. Values are means (%) ± s.e.m.

| Treatment: | 0 | 5 | 10 | 30 |
|---|---|---|---|---|
| Biomass component: | | | | |
| *Kobresia* | 1.60 ± 0.10 | 1.74 ± 0.12 | 1.69 ± 0.06 | 1.76 ± 0.17 |
| Graminoids[a] | 1.21 ± 0.09 | 1.27 ± 0.09 | 1.54 ± 0.11 | 1.69 ± 0.09 |
| Forbs[a] | 1.52 ± 0.04 | 1.67 ± 0.13 | 1.77 ± 0.05 | 1.93 ± 0.10 |

[a] Significant treatment effect at $P < 0.01$.

Extractable soil cations were dominated by $Ca^{2+}$, with $Mg^{2+}$ making up the next greatest contribution (Table 2), indicating that the soil buffering system was dominated by base cations. Extractable $Al^{3+}$ was a relatively minor component of the soil cation pool. The N treatments did not influence the concentrations of extractable cations in 2008 nor were the levels of extractable cations different from the pretreatment levels measured in 2006 (data not shown). However there was a trend for all of the base cations to have lower means in the 30 kg N ha$^{-1}$ yr$^{-1}$ treatment in 2008, which was not apparent in 2006. Soil pH values did not change with the N treatments nor between 2006 and 2008 (mean = 5.83 ± 0.06 s.e.m.), but there was a significant microsite influence (block effect, $F = 7.5$, $P = 0.002$).

## 4. Discussion

The determination of a N critical load for vegetation change was greatly facilitated by the response of a relatively abundant sedge of alpine dry meadow communities, *C. rupestris*. Increases in the cover of this N indicator species were proportional to the amount of N added. The rate of increase in cover plotted as a function of N input provided a N critical load of 3 kg N ha$^{-1}$ yr$^{-1}$. This result is very similar to the N critical load evaluation for a dry meadow on Niwot Ridge, approximately 45 km south (Bowman et al., 2006), with a N critical loads for vegetation change at 4 kg N ha$^{-1}$ yr$^{-1}$ and whole community response at 10 kg N ha$^{-1}$ yr$^{-1}$. These empirically derived N critical loads indicate vegetation changes are already ongoing on the east side of the continental divide in the Colorado Front Range. The current N deposition rates for the Chapin Pass research site, and most of the alpine areas of the eastern side of the continental divide from Rocky Mountain National Park to the south along the Denver airshed, are in excess of this critical load (Baron et al., 2000; Williams and Tonnessen, 2000; Burns, 2003; Baron, 2006). Much of this area is designated as Class I and given special protection by the Clean Air Act Amendments of 1977 (NPS ARD, 2002).

Initially we anticipate that diversity of vascular plant species will increase in most alpine communities as N deposition increases over background levels, based on responses in N fertilization experiments (Theodose and Bowman, 1997; Molau and Alatalo, 1998; Heer and Körner, 2002; Bowman et al., 2006; Olofsson and Shams, 2007), as well as theoretical considerations of the relationship between resource supply and diversity (Loreau et al., 2002). As nitrophilic species become more dominant, however, diversity will decrease with more rare species excluded by competition (Suding et al., 2005). Decreasing diversity due to N deposition has been reported in numerous ecosystems, primarily in developed countries with deposition rates >10 kg N ha$^{-1}$ yr$^{-1}$ (Stevens et al., 2004; Bobbink et al., 2010). Critical loads for similar high elevation grassland systems in Europe have generally been set

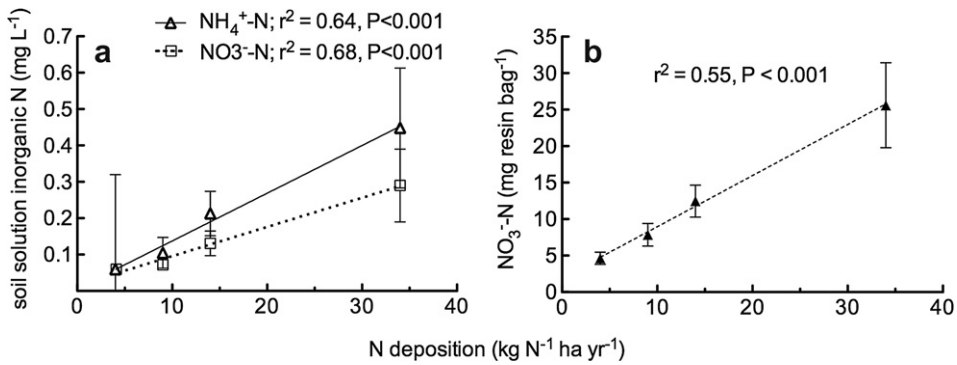



**Fig. 3.** Changes in soil solution inorganic N (a) and resin bag $NO_3^-$–N (b) from plots in an alpine dry meadow in Rocky Mountain National Park subjected to 3 years of ambient deposition (control), and additions of 5, 10, and 30 kg N $ha^{-1}$ $yr^{-1}$. Symbols are means ± s.e.m. ($n = 5$).

at higher levels (~10 kg N $ha^{-1}$ $yr^{-1}$, Achermann and Bobbink, 2003) than suggested here (3 kg N $ha^{-1}$ $yr^{-1}$), and it is possible that initial changes in species composition have already occurred in alpine grasslands in some parts of Europe. Stevens et al. (2004) suggested many low elevation grasslands in the U.K. have already lost plant species as a result of current N deposition rates between 5 and 30 kg N $ha^{-1}$ $yr^{-1}$, with as much as a 23% loss at an average deposition rate for all grasslands of 17 kg N $ha^{-1}$ $yr^{-1}$.

While there is evidence to support ongoing changes in the abundance of plant species in the southern Rocky Mountains as a result of current N deposition rates, thresholds for the response of soil metrics related to acidification do not appear to be exceeded at this time. Ecosystem uptake of inorganic N at loading rates up to 10 kg $ha^{-1}$ $yr^{-1}$ appears to be sufficient to minimize $NO_3^-$ leaching in dry meadow communities, as indicated by the lack of change in inorganic N concentrations in soil water and in resins placed below the main rooting zone. This apparent stabilization was not entirely the result of increases in plant uptake, as changes in aboveground N uptake combined with estimated belowground N uptake (assumed to be 1.5× aboveground (Fisk et al., 1998)), could not account for disappearance of all of N added. Although NPP of dry meadow and other alpine plant communities have been assumed to be limited by the supply of N (Bowman et al., 1993, 1995), there was no significant increase of aboveground biomass to the N inputs, and even when significant increases have been noted, interannual variation in NPP was greater than the N treatment effect (Bowman et al., 2006). The previous investigations of N limitation of NPP in these ecosystems have used higher inputs of N, and the majority of the biomass response was the result of a turnover in species composition. This turnover resulted in a higher abundance of nitrophilic species with greater capacity to increase biomass as N supply increased (Theodose and Bowman, 1997). Thus the stabilization of N seen in the present experiment is probably the result of a combination of greater uptake by microbial biomass (Fisk and Schmidt, 1996) and possibly by soil organic matter (Davidson et al., 2003). Changes in litter and soil organic matter chemistry, i.e. decreases in C:N ratios, will likely have positive feedbacks to N cycling rates and enhanced pools of soil inorganic N are likely to occur (Baron et al., 2000; Bowman, 2000).

**Table 2**
Extractable cation concentrations from soils collected in year 3 of an N addition treatment of 0 (control), 5, 10, and 30 kg N $ha^{-1}$ $yr^{-1}$ in an alpine dry meadow, Rocky Mountain National Park. Values are mg/kg dry mass soil ± s.e.m.

| Treatment: | 0 | 5 | 10 | 30 |
|---|---|---|---|---|
| Cation: | | | | |
| $Ca^{2+}$ | 7631 ± 1193 | 7667 ± 1352 | 7773 + 1206 | 5707 ± 351 |
| $Mg^{2+}$ | 809 ± 114 | 864 ± 164 | 887 ± 157 | 628 ± 45 |
| $K^+$ | 240 ± 43 | 244 ± 45 | 250 ± 37 | 179 ± 32 |
| $Na^+$ | 31 ± 11 | 30 ± 9 | 30 ± 9 | 13 ± 7 |
| $Mn^{2+}$ | 26 ± 5 | 29 ± 6 | 30 ± 9 | 18 ± 5 |
| $Al^{3+}$ | 3.8 ± 1.2 | 10.9 ± 5.1 | 7.5 ± 3.5 | 10.9 ± 6.3 |
| $Fe^{3+}$ | 2.4 ± 1.0 | 1.6 ± 0.5 | 2.1 ± 0.9 | 1.3 ± 0.7 |

The threshold for increases in $NO_3^-$ leaching below the rooting zone was estimated at 9 kg N $ha^{-1}$ $yr^{-1}$, and for increases in soil solution $NO_3^-$ at 14 kg $ha^{-1}$ $yr^{-1}$, using a conservative estimate that there was no impact of ambient N deposition on $NO_3^-$ leaching in vegetated soils. Above these thresholds the biotic and abiotic sinks for N deposition are exceeded. Increases in soil $NO_3^-$ leaching can initiate acidification, as soil cations are removed from cation exchange sites and replaced by protons (van Breemen et al., 1983; Binkley and Richter, 1987). Increases in $NH_4^+$ can enhance rates of nitrification, which will also acidify soils. There was no indication that acidification is currently occurring within the treatment plots at the Chapin Pass experimental site after 3 years, as extractable basic cation concentrations were not significantly affected by the treatments, nor did soil pH decrease. Soil acidification was noted after 11 years of experimental N additions above a threshold of 20 kg N $ha^{-1}$ $yr^{-1}$ at Niwot Ridge (Lieb et al., 2011), as indicated by significant decreases in base cations, soil pH, and acid neutralizing capacity, as well as increases in extractable aluminum. Generally levels of extractable base cations are higher in soils at the Chapin Pass site relative to Niwot Ridge. Soil acidification, losses of nutrient cations, and increases in soluble Al can increase susceptibility to stress, lower growth rates, and increase mortality in plants (Aber et al., 1998; Driscoll et al., 2001; Högberg et al., 2006; Bowman et al., 2008). Long-term inputs of low levels of N deposition can lower the thresholds for acidification as N builds up in the soil organic matter pool, enhancing internal N cycling rates and potentially increasing nitrification and leaching of $NO_3^-$.

The metrics used to establish N critical loads should consider the long-term ecological implications of maintaining N deposition rates at a given level (Porter et al., 2005). For relatively pristine areas such as national parks and wilderness areas, using sensitive vegetation based N critical loads, such as those described here and in Bowman et al. (2006), or lichen composition and chemistry (Geiser et al., 2010), will help protect and maintain natural plant communities that evolved under low nitrogen conditions. N critical loads will also help prevent more severe and relatively irreversible changes, such as acidification, from occurring. Once base cations are depleted, it may take decades to centuries of weathering and deposition to replace them. Recovery from acidification due to high levels of S deposition has been ongoing in industrialized regions that have reduced S emissions, but this recovery has been slowed by continued, and in some cases, enhanced N deposition (Stoddard et al., 1999; Bouwman et al., 2002; Warby et al., 2009). Preventing acidification of soils and surface waters in regions exhibiting initial

symptoms of ecological changes due to N deposition should be an important goal of land managers and air quality policy makers.

## 5. Conclusions

The critical loads we estimated for vegetation change (3 kg N $ha^{-1}$ $yr^{-1}$) and $NO_3^-$ leaching (9–14 kg N $ha^{-1}$ $yr^{-1}$) for alpine ecosystems of Rocky Mountain National Park are lower than most forest and shrubland ecosystems, but similar to other infertile ecosystems (Bobbink et al., 2010). The results indicate that changes in vegetation are already occurring in the park, similar to reports for neighboring areas (Bowman et al., 2006) and for aquatic biota in the park (Baron, 2006). No losses of soil cations or increases in soil pH were found in treatment plots, but sustained enhancement of $NO_3^-$ leaching may eventually lead to more severe and less reversible geochemical changes in soils.

## Acknowledgments

We thank Isabel Ashton, Jane Smith, Jenifer Hall-Bowman, Gordon Bowman, Miles Bowman, Courtney Meier, Melissa Maxa, Kaleb Keyserling, Samantha Swatling-Holcomb, Evan Fricke, Anna Lieb, and Ben Kamark for field assistance. Laboratory analyses were expertly performed by the staff of the Niwot Ridge LTER program, supervised by Chris Seibold, the Laboratory for Environmental and Geological Studies, and Chris Washenberger/Diana Nemergut (CHN analyses). Constructive comments on a previous version of this manuscript were provided by three anonymous reviewers and Harrison Carpenter's Spring 2012 Graduate Writing Seminar course.. Funding was provided by the National Park Service, Air Resources Division, through a Rocky Mountain Cooperative Ecosystem Studies Units grant.

## References

Aber, J., McDowell, W., Nadelhoffer, K., Magill, A., Berntson, G., Kamakea, M., McNulty, S., Currie, W., Rustad, L., Fernandez, I., 1998. Nitrogen saturation in temperate forest ecosystems: hypotheses revisited. BioScience 11, 921–934.

Achermann, B., Bobbink, R. (Eds.), 2003. Empirical Critical Loads for Nitrogen. Environmental Documentation No. 164 Air. Swiss Agency for Environment, Forest and Landscape SAEFL, Berne, p. 327.

Baron, J.S., Rueth, H.M., Wolfe, A.M., Nydick, K.R., Allstott, E.J., Minear, J.T., Moraska, B., 2000. Ecosystem responses to nitrogen deposition in the Colorado Front Range. Ecosystems 3, 352–368.

Baron, J.S., 2006. Hindcasting nitrogen deposition to determine an ecological critical load. Ecol. Appl. 16, 433–439.

Binkley, D., Högberg, P., 1997. Does atmospheric deposition of nitrogen threaten Swedish forests? For. Ecol. Manage. 92, 119–152.

Binkley, D., Richter, D., 1987. Nutrient cycles and H+ budgets of forest ecosystems. Adv. Ecol. Res. 16, 1–51.

Bobbink, R., Hornung, M., Roelofs, J.G.M., 1998. The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation. J. Ecol. 86, 717–738.

Bobbink, R., Hicks, K., Galloway, J., Spranger, T., Alkemade, R., Ashmore, M., Bustamante, M., Cinderby, S., Davidson, E., Dentener, F., Emmett, B., Erisman, J.-W., Fenn, M., Gilliam, F., Nordin, A., Pardo, L., De Vries, W., 2010. Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis. Ecol. Appl. 20, 30–59.

Bouwman, A.F., Van Vuuren, D.P., Derwent, R.G., Posch, M., 2002. A global analysis of acidification and eutrophication of terrestrial ecosystems. Water, Air, Soil Pollut. 141, 349–382.

Bowman, W.D., Bilbrough, C.J., 2001. Influence of a pulsed nitrogen supply on growth and nitrogen uptake in alpine graminoids. Plant Soil 233, 283–290.

Bowman, W.D., Steltzer, H., 1998. Positive feedbacks to anthropogenic nitrogen deposition in Rocky Mountain alpine tundra. Ambio 27, 514–517.

Bowman, W.D., Theodose, T.A., Schardt, J.C., Conant, R.T., 1993. Constraints of nutrient availability on primary production in two alpine tundra communities. Ecology 74, 2085–2097.

Bowman, W.D., Theodose, T.A., Fisk, M.C., 1995. Physiological and production responses of plant growth forms to increases in limiting resources in alpine tundra: implications for differential community response to environmental change. Oecologia 101, 217–227.

Bowman, W.D., Gartner, J.L., Holland, K., Wiedermann, M., 2006. Nitrogen critical loads for alpine vegetation and terrestrial ecosystem response – are we there yet? Ecol. Appl. 16, 1183–1193.

Bowman, W.D., Cleveland, C.C., Halada, L., Hreško, J., Baron, J.S., 2008. Negative impact of nitrogen deposition on soil buffering capacity. Nat. Geosci. 1, 767–770.

Bowman, W.D., 1992. Inputs and storage of nitrogen in winter snowpack in an alpine ecosystem. Arct. Alp. Res. 24, 211–215.

Bowman, W.D., 2000. Biotic controls over ecosystem response to environmental change in alpine tundra of the Rocky Mountains. Ambio 29, 396–400.

Burns, D.A., Blett, T., Haeuber, R., Pardo, L.H., 2008. Critical loads as a policy tool for protecting ecosystems from the effects of air pollutants. Front. Ecol. Environ. 6, 156–159.

Burns, D.A., 2003. Atmospheric nitrogen deposition in the Rocky Mountains of Colorado and southern Wyoming – a review and new analysis of past study results. Atmos. Environ. 37, 921–932.

Chadwick, O.A., Chorover, J., 2001. The chemistry of pedogenic thresholds. Geoderma 100, 321–353.

Clark, C.M., Tilman, D., 2008. Loss of plant species after chronic low-level nitrogen deposition to prairie grasslands. Nature 451, 712–715.

Clow, D.W., 2010. Changes in the timing of snowmelt and streamflow in Colorado: a response to recent warming. J. Clim. 23, 2293–2306.

Davidson, E.A., Chorover, J., Dail, D.B., 2003. A mechanism of abiotic immobilization of nitrate in forest ecosystems: the ferrous wheel hypothesis. Glob. Change Biol. 9, 228–236.

Dentener, F., Drevet, J., Lamarque, J.F., Bey, I., Eickout, B., et al., 2006. Nitrogen and sulfur deposition on regional and global scales: a multimodel evaluation. Global Biogeochem. Cy. 20, GB4003.

Driscoll, C.T., Lawrence, G.B., Bulger, A.J., Butler, T.J., Cronan, C.S., Eagar, C., Lambert, K.F., Likens, G.E., Stoddard, J.L., Weathers, K.C., 2001. Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. BioScience 51, 180–198.

Fenn, M.E., Haeuber, R., Tonnesen, G.S., Baron, J.S., Grossman-Clarke, S., Hope, D., Jaffe, D.A., Copeland, S., Geiser, L., Rueth, H.M., Sickman, J.O., 2003. Nitrogen emissions, deposition, and monitoring in the western United States. BioScience 53, 391–403.

Fisk, M.C., Schmidt, S.K., 1996. Microbial responses to nitrogen additions in alpine tundra soil. Soil Biol. Biochem. 28, 751–755.

Fisk, M.C., Schmidt, S.K., Seastedt, T.R., 1998. Topographic patterns of above- and belowground production and N cycling in alpine tundra. Ecology 79, 2253–2266.

Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P., Sutton, M.A., 2008. Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science 320, 889–892.

Geiser, L.H., Neitlich, P.N., 2007. Air pollution and climate gradients in western Oregon and Washington indicated by epiphytic macrolichens. Environ. Pollut. 145, 203–218.

Geiser, L.H., Jovan, S.E., Glavich, D.A., Porter, M.K., 2010. Lichen-based critical loads for atmospheric nitrogen deposition in Western Oregon and Washington Forests, USA. Environ. Pollut. 158, 2412–2421.

Gough, L., Osenberg, C.W., Gross, K.L., Collins, S.L., 2000. Fertilization effects on species density and primary production in herbaceous plant communities. Oikos 89, 428–439.

Groffman, P.M., Baron, J.S., Gold, A.J., Gunderson, L.H., Levinson, B.M., Palmer, M.A., Paerl, H.W., Peterson, G.D., Reynolds, J.F., Turner, M.G., Weathers, K.C., Weins, J., 2006. Ecological thresholds: the key to successful environmental management or an important concept with no practical application. Ecosystems 9, 1–13.

Heer, C., Körner, C., 2002. High elevation pioneer plants are sensitive to mineral nutrient addition. Basic Appl. Ecol. 3, 39–47.

Högberg, P., Fan, H., Quist, M., Binkley, D., Tamm, C.O., 2006. Tree growth and soil acidification in response to 30 years of experimental nitrogen loading on boreal forest. Global Change Biol. 12, 489–499.

Komárková, V., 1979. Alpine Vegetation of the Indian Peaks Area, Front Range, Colorado Rocky Mountains. Flora et Vegetatio Mundi, Bd VII. J Cramer, Vaduz.

Lieb, A.M., Darrouzet-Nardi, A., Bowman, W.D., 2011. Nitrogen deposition decreases acid buffering capacity of alpine soils in the southern Rocky Mountains. Geoderma 164, 220–224.

Loreau, M., Naeem, S., Inchausti, P. (Eds.), 2002. Biodiversity and Ecosystem Functioning: Synthesis and Perspectives. Oxford University Press, Oxford.

Molau, U., Alatalo, J.M., 1998. Responses of subarctic-alpine plant communities to simulated environmental change: biodiversity of bryophytes, lichens, and vascular plants. Ambio 27, 322–329.

Nilsson, I., Grennfelt, P., 1988. Critical Loads for Sulfur and Nitrogen. Report from a Workshop Held at Stokhoster, Sweden, March 19–24, 1988. Miljo Rapport 1988: 15. Nordic Council of Ministers, Copenhagen, Denmark.

NPS ARD [National Park Service, Air Resources Division], 2002. Air Quality in the National Parks, second ed. U.S. Department of Interior, Washington, DC.

Olofsson, J., Shams, H., 2007. Determinants of plant species richness in an alpine meadow. J. Ecol. 95, 916–925.

Pepin, N.C., Losleben, M.L., 2002. Climate change in the Colorado Rocky Mountains: free-air versus surface temperature trends. Int. J. Climatol. 22, 311–329.

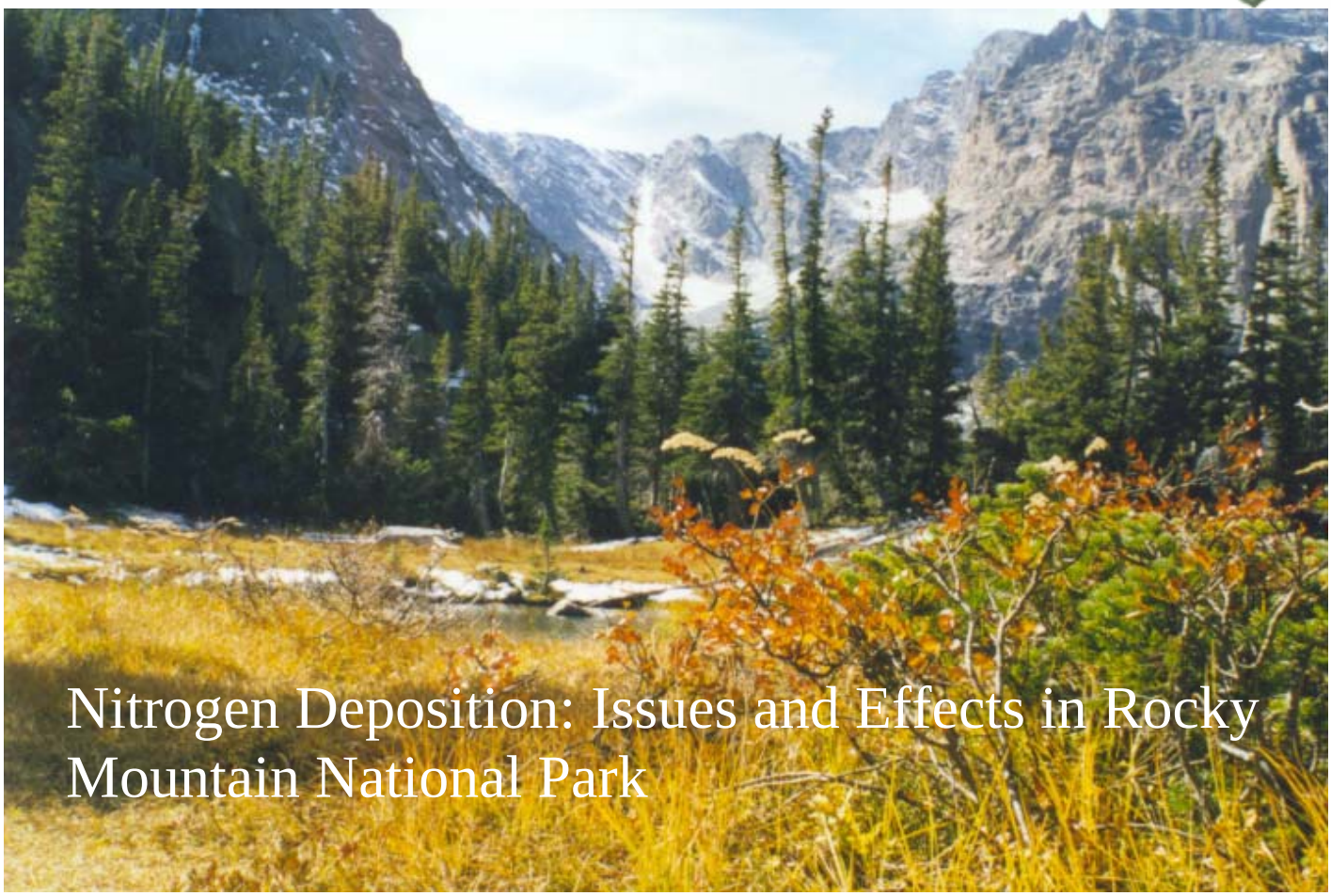
Porter, E., Blett, T., Potter, D.U., Huber, C., 2005. Protecting resources on federal lands: implications of critical loads for atmospheric deposition of nitrogen and sulfur. BioScience 55, 603–612.

Rao, L.E., Allen, E.B., 2010. Combined effects of precipitation and nitrogen deposition on native and invasive winter annual production in California deserts. Oecologia 162, 1035–1046.
Stevens, C.J., Dise, N.B., Mountford, J.O., Gowing, D.J., 2004. Impact of nitrogen deposition on the species richness of grasslands. Science 303, 1876–1879.
Stoddard, J.L., Jeffries, D.S., Lukewille, A., Clair, T.A., Dillon, P.J., Driscoll, C.T., Forsius, M., Johannessen, M., Kahl, J.S., Kellogg, J.H., Kamp, A., Mannio, D.T., Murdoch, P.S., Patrick, S., Rebsdorf, A., Skjelkvåle, B.L., Stainton, M.P., Traaen, T., van Dam, H., Webster, K.E., Weiting, J., Wilander, A., 1999. Regional trends in aquatic recovery from acidification in North America and Europe. Nature 401, 575–578.
Suding, K.N., Collins, S.L., Gough, L., et al., 2005. Functional and abundance-based mechanisms explain diversity loss due to N fertilization. Proc. Natl. Acad. Sci. USA 102, 4387–4392.
Theodose, T.A., Bowman, W.D., 1997. Nutrient availability, plant abundance, and species diversity in two alpine tundra communities. Ecology 78, 1861–1872.
Thomas, R.Q., Canham, C.D., Weathers, K.C., Goodale, C.L., 2010. Increased tree carbon storage in response to nitrogen deposition in the US. Nat. Geosci. 3, 13–17.
van Breemen, N., Mulder, J., Driscoll, C.T., 1983. Acidification and alkalinization of soils. Plant Soil 75, 283–308.
Warby, A.F., Johnson, C.E., Driscoll, C.T., 2009. Continuing acidification of organic soils across the Northeastern USA: 1984–2001. Soil Sci. Soc. Am. J. 73, 274–284.
Weathers, K.C., Simkin, S.M., Lovett, G.M., Lindberg, S.E., 2006. Empirical modeling of atmospheric deposition in mountainous landscapes. Ecol. Appl. 16, 1590–1607.
Webber, P.J., May, D.E., 1977. The magnitude and distribution of below ground plant structures in the alpine tundra of Niwot Ridge, Colorado. Arct. Alp. Res. 9, 157–174.
Williams, M.W., Tonnessen, K.A., 2000. Critical loads for inorganic nitrogen deposition in the Colorado Front Range, USA. Ecol. Applic. 10, 1648–1665.
Yoshida, L.C., Allen, E.B., 2004. $^{15}$N uptake by mycorrhizal *Artemisia californica* and the invasive *Bromus madritensis* of a N-eutrophied shrubland. Biol. Fert. Soils 39, 243–248.

# EXHIBIT 14

Rocky Mountain National Park

National Park Service
Department of the Interior



# Nitrogen Deposition: Issues and Effects in Rocky Mountain National Park

Updated March 2005

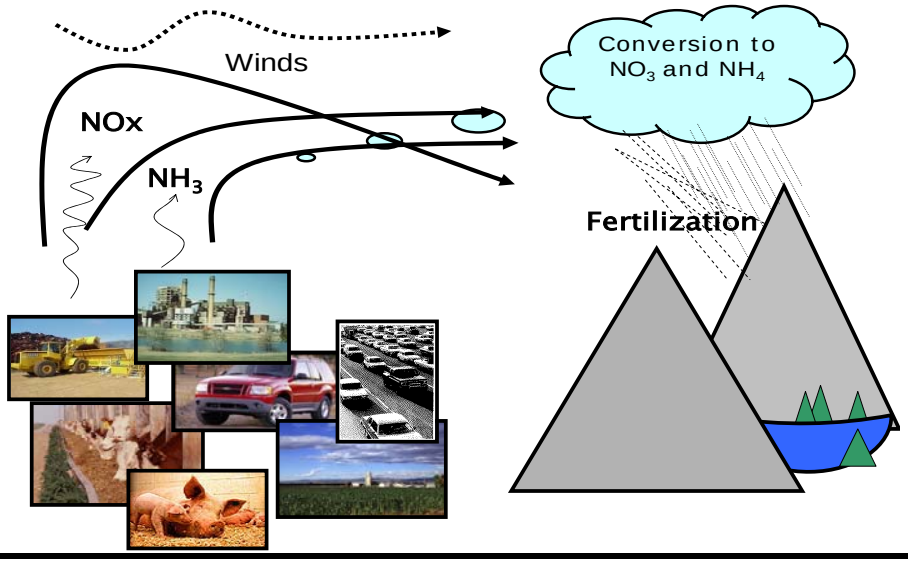
## Background

Rocky Mountain National Park is downwind of many man-made sources of air pollution. While the Park's air is relatively clean compared to other national parks near large cities, pollutants from sources in Colorado's Front Range, as well as from other areas in the U.S. and abroad, are carried into the Park on the wind. These pollutants are deposited in rain, snow, and as dry particles. Researchers from the U.S. Geological Survey and National Park Service have been working for over 20 years to determine whether the amounts of air pollution found in Rocky Mountain National Park are sufficient to affect Park ecosystems. Adequate data now exist to show that soils, waters, and plants are beginning to show evidence of changes from nitrogen deposition. Nitrogen pollution in the air comes from vehicles, industrial emissions, and agricultural sources such as farm fertilizer and animal waste (figure 1). Nitrogen carried in air currents and deposited in ecosystems can act as a fertilizer, favoring some types of plants and leaving others at a disadvantage. This creates an imbalance in natural ecosystems, and it is not known whether these changes can be reversed even if nitrogen deposition is reduced later. Nitrogen uses up natural buffering agents in waters and soils, leaving Park ecosystems vulnerable to future acidification. Nitrogen pollution also contributes to visibility reducing haze and formation of ozone, a pollutant harmful to human health and vegetation.

**Nitrogen Loading in Rocky Mountain National Park**

National Park ecosystems are managed to be as natural or **unimpaired** as possible. Man-made air pollutants may cause unnatural ecosystem changes that can be described as exceeding a **critical load**. Ecosystems in Rocky Mountain National Park are beginning to reflect changes caused by nitrogen deposition. Effects to ecosystem structure (species composition) and function (soil and water and tree chemistry) have been documented in some areas of the Park, and this indicates that nitrogen deposition is above critical loads for sensitive Park ecosystems. Total annual (wet and dry) nitrogen deposition monitored in the park since the mid 1990s averages around 3.9 kg/ha/yr. Pre-industrial or "natural" levels of nitrogen deposition are estimated to be about 20 times lower than current deposition, at around 0.2 kg/ha/yr.

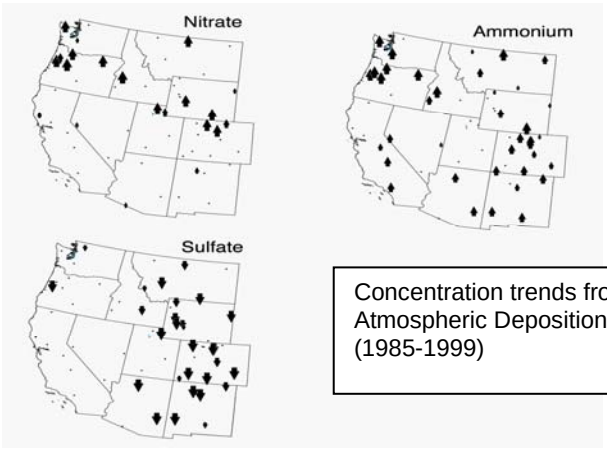
**Figure 1: Unnatural Fertilization of Sensitive Park Ecosystems**
Nitrogen in the form of nitrogen oxides ($NO_x$) and ammonium ($NH_4$) is carried by the wind until it deposits in high-elevation areas. The extra nitrogen can act as a fertilizer, causing unnatural changes to water and soil chemistry and plants and animals in the ecosystem. (figure source: J. Baron, USGS)




## Sensitive Ecosystems

High elevation ecosystems at Rocky Mountain National Park are more vulnerable to atmospheric nitrogen deposition than many ecosystems in the eastern U.S. or in other countries. This is because the granitic bedrock and shallow soils found in the Park don't provide much chemical buffering. In addition, short growing seasons at high elevation limit the amount of time plants have to absorb nitrogen during the year. These plants evolved under very low nitrogen conditions, so they are more accustomed to low nitrogen environments. High elevation ecosystems in Rocky Mountain National Park currently show subtle changes from the effects of deposition (see sidebar at right). Studies from areas with higher nitrogen deposition levels, like the eastern U.S. and Europe, indicate that detrimental effects to aquatic and terrestrial ecosystems in the Park will continue to be seen at current deposition levels and effects may increase in severity if nitrogen continues to increase at current rates (figure 2). The National Park Service and air quality regulators at the State of Colorado and the Environmental Protection Agency are working together to determine options for reducing nitrogen deposition impacts to the Park.

**Figure 2: Nitrogen Trends in the Western U.S.**
The concentration of nitrogen (nitrate and ammonium) in rain and snow has been increasing in many areas of the western U.S., including Rocky Mountain National Park, while sulfate has been decreasing (figure source: Clow and others. 2003. Water Resources Research 39:6)




Concentration trends from National Atmospheric Deposition Program (NADP) data (1985-1999)

## Facts about excess nitrogen in Rocky Mountain National Park

- Nitrogen concentration in the Park's rain and snow has been increasing (figure 2). Nitrogen deposition (concentration x precipitation) has been increasing by about 2% per year over the last two decades in the Park.
- There is more nitrogen deposited in high elevation ecosystems at the Park than plants can use, and excess nitrogen is leaking into Park lakes and streams at certain times of the year.
- Chemical changes are occurring now in surface waters, soils, and trees on the east side of the Park.
- Lake sediment analysis shows that excess nitrogen deposition has altered diatom species composition. This change began to occur around 1950. Diatoms are algae, small oxygen producing plants in lakes.
- Nitrogen deposition has been shown in other parts of the country to use up natural buffering chemicals in lakes and soils. Eventually these resources become acidic and cease to support sensitive species such as fish. Ecologists and data modelers are working to determine how long it would take, at current rates of nitrogen deposition, for this to occur in Rocky Mountain National Park.
- Experiments on nearby Niwot Ridge show that increasing nitrogen changes the species of plants that live on the tundra. Grasses and sedges outcompete flowering plants, a change that could reduce habitat for some animals and diminish alpine flowers in the Park.

**More information about nitrogen deposition research, monitoring, and ecosystem effects at Rocky Mountain National Park is available at:**
**http://co.water.usgs.gov/lochvale/index.html**
**http://www.nrel.colostate.edu/projects/lvws/pages/homepage.htm**
**http://www2.nature.nps.gov:82/scripts/synth.dll**

# EXHIBIT 15

EPA

http://www.epa.gov/airquality/ozonepollution/ecosystem.html

## Ground-level Ozone
# Ecosystem Effects

Ozone also affects sensitive vegetation and ecosystems, including forests, parks, wildlife refuges and wilderness areas. In particular, ozone harms sensitive vegetation, including trees and plants during the growing season.

Plant species that are sensitive to ozone and potentially at an increased risk from exposure include trees such as black cherry, quaking aspen, ponderosa pine and cottonwood. These trees are found in many areas of the country.

Ground level ozone can have harmful effects on sensitive vegetation and ecosystems. When sufficient ozone enters the leaves of a plant, it can:

- Interfere with the ability of sensitive plants to produce and store food.
- Visibly damage the leaves of trees and other plants, harming the appearance of vegetation in urban areas, national parks, and recreation areas.

In addition to reduced tree growth and visible injury to leaves, continued ozone exposure over time can lead to increased susceptibility of sensitive plant species to disease, damage from insects, effects of other pollutants, competition, and harm from severe weather. These effects can also have adverse impacts on ecosystems, including loss of species diversity and changes to habitat quality and water and nutrient cycles.

For more information on how EPA works to reduce ground level ozone, visit the Ozone Standards page.

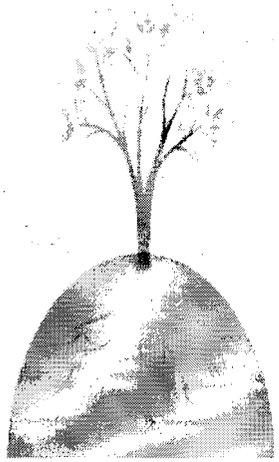
**Ozone Effects on Plants**

Recent systematic surveys by the USDA US Forest Service continue to document widespread injury on sensitive bioindicator plants.

*Black Cherry*
*Courtesy, USDA FS FIA*

Many studies have documented diagnostic leaf injury due to ozone in the field, including remote wilderness areas. However, damage from ozone is not always visible on leaves and growth decline can occur without these symptoms.

*Tulip Poplar*
*USDA PLANTS Database*



Ground level ozone is absorbed by the leaves of plants, where it can reduce photosynthesis, damage leaves and slow growth. It can also make sensitive plants more susceptible to certain diseases, insects, harsh weather and other pollutants.

Last updated on Monday, April 02, 2012

# EXHIBIT 16

# United States Department of the Interior

NATIONAL PARK SERVICE
Air Resources Division
P.O. Box 25287
Denver, CO 80225-0287


IN REPLY REFER TO:

N3615 (2350)

August 20, 2013

Ms. Margaret Earnest
Office of Air
Texas Commission on Environmental Quality
P.O. Box 13087
Austin, TX 78711-3087

Dear Ms. Earnest:

Thank you for the opportunity to review and comment on the Texas Commission on Environmental Quality (TCEQ)'s proposed Five Year Regional Haze State Implementation Plan (SIP) Revision. The proposed Five-Year Review demonstrates that Texas has achieved emissions reductions from source sectors included in the Long Term Strategy in the Texas Regional Haze SIP. However the Review does not demonstrate that Texas is implementing all the reasonable control measures necessary to reduce Texas' proportional contribution to visibility impairment at Class I areas in Texas and impacted by Texas. Our 2008 comments on the draft SIP requested more complete justification on why Texas was relying on existing state and federal requirements and why no additional controls were required for regional haze. Since EPA has not taken action on Texas' 2009 Regional Haze SIP, we do not know if EPA accepts that Texas is implementing all reasonable controls measures.

Below we compare TCEQ' review to the requirements of 40 CFR 51.308(g) and EPA's 2013 General Principles for the Five-Year Regional Haze Progress Report. In our attached comments we discuss concerns that we raised with the 2008 draft SIP that were not addressed in the 2009 SIP submittal to EPA.

**Visibility Trends**

In Chapter 3, TCEQ provides a summary table showing that visibility at Big Bend and Guadalupe Mountains National Parks (NP) on the 20% worst days improved slightly between the baseline period 2000-2004 and the subsequent 5 year period 2005-2009. On the 20% best days, visibility was either slightly better or slightly worse than the baseline period. We request that Texas discuss the pollutant contributions to visibility impairment and how those contributions

have changed over the decade. TCEQ needs to establish which pollutants are most important to control to improve visibility on the 20% worst days, and which pollutants are responsible for the slight degradation on the 20% best days at Big Bend NP. TCEQ has included the IMPROVE report of 2005-2009 data as an appendix. We request that TCEQ discuss in the progress report the pollutant contributions for the Class I areas in Texas and impacted by Texas emissions, so that the reader understands how the emissions reductions discussed in Chapter 2 relate to visibility improvement.

EPA's 2013 General Principles for the Five-Year Regional Haze Progress Report instructs states to use the most recent IMPROVE data. IMPROVE data is currently available through 2011. For many Class I areas, including Big Bend and Guadalupe Mountains National Parks, visibility improvement is greater in the most recent 2007-2011 period than the 2005-2009 period. We request that TCEQ discuss the IMPROVE data through 2011.

**Best Available Retrofit Technology (BART)**

In Chapter 2, TCEQ asserts that none of the 125 potentially BART-eligible sources were required to install controls for BART because permitted emissions do not contribute to an impact at a Class I area greater than a 0.5 dv contribution threshold. As we commented in 2008, given the large number of sources, TCEQ should have considered the cumulative impacts of these sources and used a lower threshold to consider controls for an individual source. Otherwise, the cumulative impact of these sources is not addressed.

TCEQ asserts that to date, under the requirements of the Clean Air Interstate Rule (CAIR), Electric Generating Units (EGU) in Texas have reduced sulfur dioxide ($SO_2$) emissions by 23% and nitrogen oxide ($NO_x$) emissions by 44%. We request that TCEQ provide additional source specific information that indicates when sources installed controls or when they will install controls. From the information provided, we cannot tell if Texas is on track to meet the EGU reductions included in the CENRAP and WRAP modeling that was used to establish reasonable progress goals in Texas and neighboring states.

**Status of Control Measures**

Chapter 2 discusses consent decrees that have been implemented after the CENRAP modeling and that represent additional emissions reductions that were not included in the reasonable progress goals. However, it is not clear if the inventories in Chapter 4 include the emission reductions from these latest consent decrees and rule requirements (e.g. Owens Glass, MATS rule), or only those controls included in the CENRAP inventories. For example, are emissions reductions from the Texas Emissions Reduction Plans and grants programs (Chapter 2.9) included in inventories reported in Chapter 4? Please clarify.

Section 2.6.1 should be updated to include latest EPA and court actions on CAIR and the Cross State Air Pollution Rule.

**Emissions Inventory**

TCEQ presents emissions inventories for 2005, 2008, and 2011. We commend TCEQ for including the 2011 National Emissions Inventory data. Please provide tables with the 2002 and 2018 inventory data from the 2009 SIP so that the reader can compare previous and current

inventory projections. We agree that there are differences in inventory assumptions between years that complicate interpretation; these differences should be identified.

As discussed in the attached comments, in its 2009 SIP submittal TCEQ noted that CENRAP overestimated $SO_2$ emissions from areas sources by 96,000 tons per year (tpy). It appears that in the progress report, TCEQ did not correct this error in Figure 4-1 for 2002 and 2018 $SO_2$ emissions. Please clarify.

According to the Progress Report (pp 4-5):

> The 2008 area source inventory was enhanced with additional categories as part of the commission's initiative to improve inventory estimations. In 2005, limited categories were used for the oil and gas inventory. The 2008 inventory was expanded with emissions estimates from additional oil and gas categories and improved fertilizer and livestock categories. These improvements combined with an increase in oil and gas activity increased the 2008 VOC emissions estimates. The improved agricultural estimates resulted in a decrease in the ammonia estimates.

Why did area source emissions of $NO_X$ and VOC decrease between 2008 and 2011? Please present oil and gas emissions separately from all area source emissions so that the reader can understand the contributions from oil and gas. In other states, emissions due to oil and gas are increasing, often in the same remote and rural areas where national parks are located. Please present data specific to oil and gas and clarify if these data account for the refineries consent decree.

**Natural Visibility Conditions**

In its 2009 SIP submittal, TCEQ proposed revisions to the default natural visibility conditions. In the proposed Five-Year Review, TCEQ does not discuss natural conditions. Visibility improvement in Figures 5-1 through 5-4 is truncated to the period 2002-2018 and does not show the reader the full glidepath to natural visibility conditions by 2064. Please use the same vertical axis for the 20% worst and 20% best visibility days in Figures 5-1 through 5-4, including glidepaths to 2064. Please show the average deciview for the 20% worst days for each year and rolling 5-year averages.

In our attached comments we illustrate both the default and natural conditions. TCEQ estimated a higher value for natural visibility conditions on the 20% worst days than the EPA default value. Although this resulted in a shallower glidepath than the default, the CENRAP CMAQ modeling upon which Texas relied still projected that Class I areas in Texas would not meet the revised uniform rate of progress by 2018.

**Reasonable Progress**

Even after implementation of CAIR, in 2011 Texas EGU emitted 433,782 tons per year of $SO_2$ and 143,782 tons per year of NOx. It is difficult to believe that these cumulative emissions do not impair visibility in Class I areas in TX and nearby states and that additional reductions beyond those required by CAIR are not reasonable compared to costs borne by EGU in other

states. Texas has not demonstrated that it is requiring all reasonable controls necessary to address its contribution to visibility impairment at Class I areas in neighboring states.

**Summary**

We disagree with Section 5.6, Summary Assessment, that TCEQ has demonstrated that Texas' current strategy is adequate for Class I areas in Texas and in areas affected by Texas to meet all established reasonable progress goals. We request that TCEQ compare current visibility conditions to the 2018 goals for Class I areas in Texas and those Class I areas impacted by Texas to show that reductions are sufficient and on track to meet reasonable progress goals by 2018. What additional emission reductions were included in the CENRAP modeling that are enforceable but have not been implemented?

We request that TCEQ discuss in Chapter 5 the CENRAP air quality modeling using the particulate source apportionment test (PSAT). This analysis estimated states' contributions to sulfate and nitrate at each Class I area. Texas contributed up to 28% of the sulfate at neighboring Class I areas. In the attached comments, we have included charts apportioning contributions to visibility impairment at Big Bend and Guadalupe Mountains NPs, and request that Texas provide similar charts for Class I areas outside its borders.

Texas has not demonstrated that implementation of existing Texas and federal rules are the only emission reductions that are reasonable to implement by 2018 to satisfy the requirements of the regional haze rule. Without additional discussion of Texas' contribution to Class I areas outside Texas, we cannot agree that TCEQ has demonstrated that the existing SIP is adequate for continued progress toward established reasonable progress goals in other states.

We appreciate the opportunity to work closely with Texas to improve visibility at Class I national park units. If you have questions, please contact Pat Brewer at 303-969-2153 or Don Shepherd at 303-969-2075.

Sincerely,

Susan Johnson
Chief, Policy, Planning, and Permit Review Branch

Enclosure

cc:
Joe Kordzi
EPA Region 6
1445 Ross Ave., Dallas, TX 75202–2733

**NPS Comments on the 2009 Texas Regional Haze SIP not addressed in the 2013 draft Regional Haze Progress Report**

August 19, 2013

In its 2009 SIP submittal, Texas noted that:

> The area source SO2 emissions used by the CENRAP in their modeling are significantly higher than the 15,633 tons per year (tpy) reported by the TCEQ. The difference is industrial and residential coal combustion which was erroneously included in the CENRAP inventory. The TCEQ has been working with CENRAP to correct this error for future modeling, but there was not sufficient time to remodel with the more accurate TCEQ-supplied inventory. CENRAP's modeled emissions estimate is not expected to significantly impact visibility estimates for 2018 because of the relatively small contribution from these Texas sources on Class I areas.

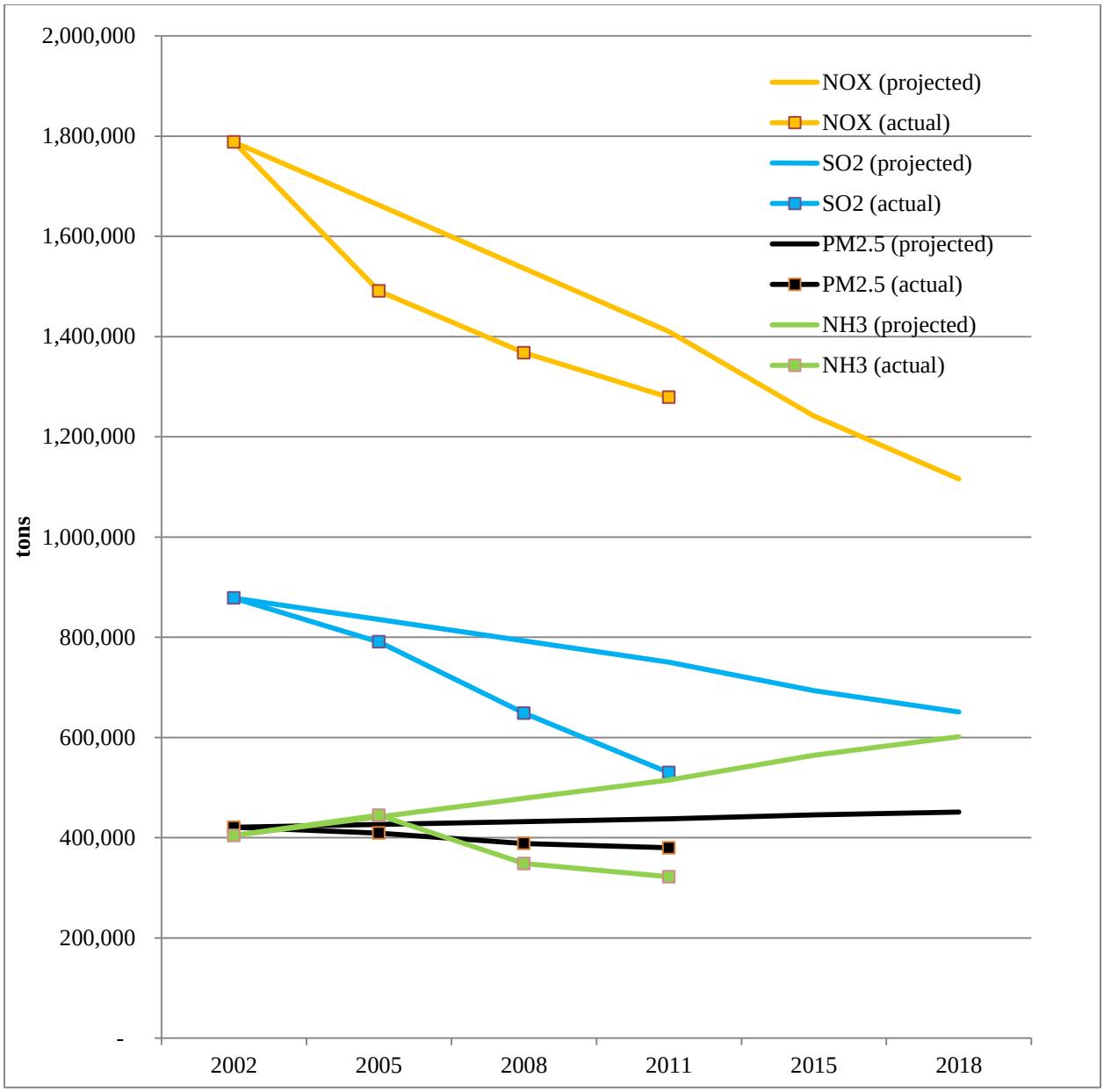
We request that Texas update this statement, "TCEQ has been working with CENRAP to correct this error for future modeling..."

CENRAP modeled 111,853 tpy of $SO_2$ from area sources, and 974,457 tpy $SO_2$ from all sources in 2002. The 96,000 tpy error is almost 10% of the $SO_2$ total. Figure 4-1 of the Progress Report appears to have used the erroneous value for 2002 $SO_2$; if that is true, then Figure 4-1 should be revised to use the correct value.

CENRAP appears to have carried the area source $SO_2$ overestimation into 2018[1] by estimating 114,138 tpy; this is a 2% increase in these incorrect emissions. Applying that same 2% increase to the correct 2002 area source $SO_2$ emissions yields 15,952 tons, a difference of 98,156 tpy, This corrected value should also be reflected in Figure 4-1 of the progress report.

Although Tables 4-1 thru 4-3 in the Progress Report show much lower (corrected?) values for area source $SO_2$ between 2005 and 2011, the 2002 and 2018 endpoints in Figure 4-1 continue to show the overestimated area source $SO_2$ estimates. We also question the value of including CO in Figure 4-1 because it causes the vertical axis to be compressed. Instead, we suggest showing ammonia emission trends because background ammonia concentration is a critical factor in particle formation. We have included below an example of how Figure 4-1 might look with corrected estimates for area source $SO_2$ and ammonia emissions (instead of CO). Our results indicate that actual emissions are tracking below the future projections.

[1] According to Texas, "The CENRAP projected the 2002 base year emissions for Texas and other central states to the 2018 future planning year primarily using the Economic Growth Analysis System (EGAS5) for non-electric generating unit point sources, area sources, and non-road mobile sources…"




Total Emissions corrected to remove the CENRAP overestimate of SO2 area sources

In its 2009 "Response to Comments" document, Texas stated:

> The EPA, NPS, and FWS questioned that CENRAP's modeled emissions estimate was not expected to significantly impact visibility estimates for 2018 because of the relatively small contribution from these Texas sources on Class I areas. The EPA, NPS and FWS commented that data presented in the SIP narrative suggested that Texas sources' emissions constitute the majority of visibility impact at the Wichita Mountains Salt Creek, and Caney Creek; and indicated that Texas sources' emissions have a great impact at White Mountain. The EPA, NPS and FWS asked that the TCEQ explain the specific difference between the reported TCEQ sulfur dioxide inventory and the CENRAP modeled inventory as well as the rationale for why TCEQ considers Texas' contribution to visibility impairment in neighboring states' Class I areas to not be significant.

> **The SIP statement that "the SO2 emissions modeled by the CENRAP are significantly higher than the 15,633 tpy reported by the TCEQ" was intended to refer specifically to the area sources of industrial and residential coal combustion that were over-represented in the CENRAP modeling inventory, not all SO2 emissions. The commission did not intend to imply that emissions or emissions contributions to visibility from its sources were insignificant. The erroneously modeled industrial and residential coal combustion sources are typically individually smaller and distant from Class I areas. As a result, their representation in the model does not significantly detrimentally affect visibility estimates or model conclusions. In response to this comment, additions were made to Chapter 7: *Emissions Inventory* and Appendix 7-1 of the SIP revision for clarity.**

We request that Texas provide support for its assumptions that, "The erroneously modeled industrial and residential coal combustion sources are typically individually smaller and distant from Class I areas. As a result, their representation in the model does not significantly detrimentally affect visibility estimates or model conclusions."

In its 2009 SIP submittal,[2] Texas noted that:

> The CAIR cap is the total allowable emissions of SO2 from EGUs in Texas under CAIR. The IPM model analysis used by CENRAP predicts that by 2018 EGUs in Texas will purchase approximately 125,000 tpy of emissions allowances from out of state. The TCEQ requested that key EGUs in Texas review and comment on the predictions of the IPM model. However, no EGU made an enforceable commitment to any particular pollution control strategy and preferred to retain the flexibility offered by the CAIR program.
>
> In the five-year periodic progress report required by 40 CFR §51.308(g), the TCEQ plans to review emissions inventory and permit information to evaluate the accuracy of the predicted emissions used in the CENRAP modeling.

What did TCEQ find?

## Natural Conditions

In its 2009 SIP submittal,[3] Texas states**, "**The TCEQ plans to work with the EPA, Federal Land Managers (FLMs), and other experts and researchers as Texas continues to refine natural condition estimates for future five-year reports and ten-year Regional Haze SIP revisions." We encourage Texas to begin that effort with the FLMs.

In its 2009 "Response to Comments" document, TCEQ stated:

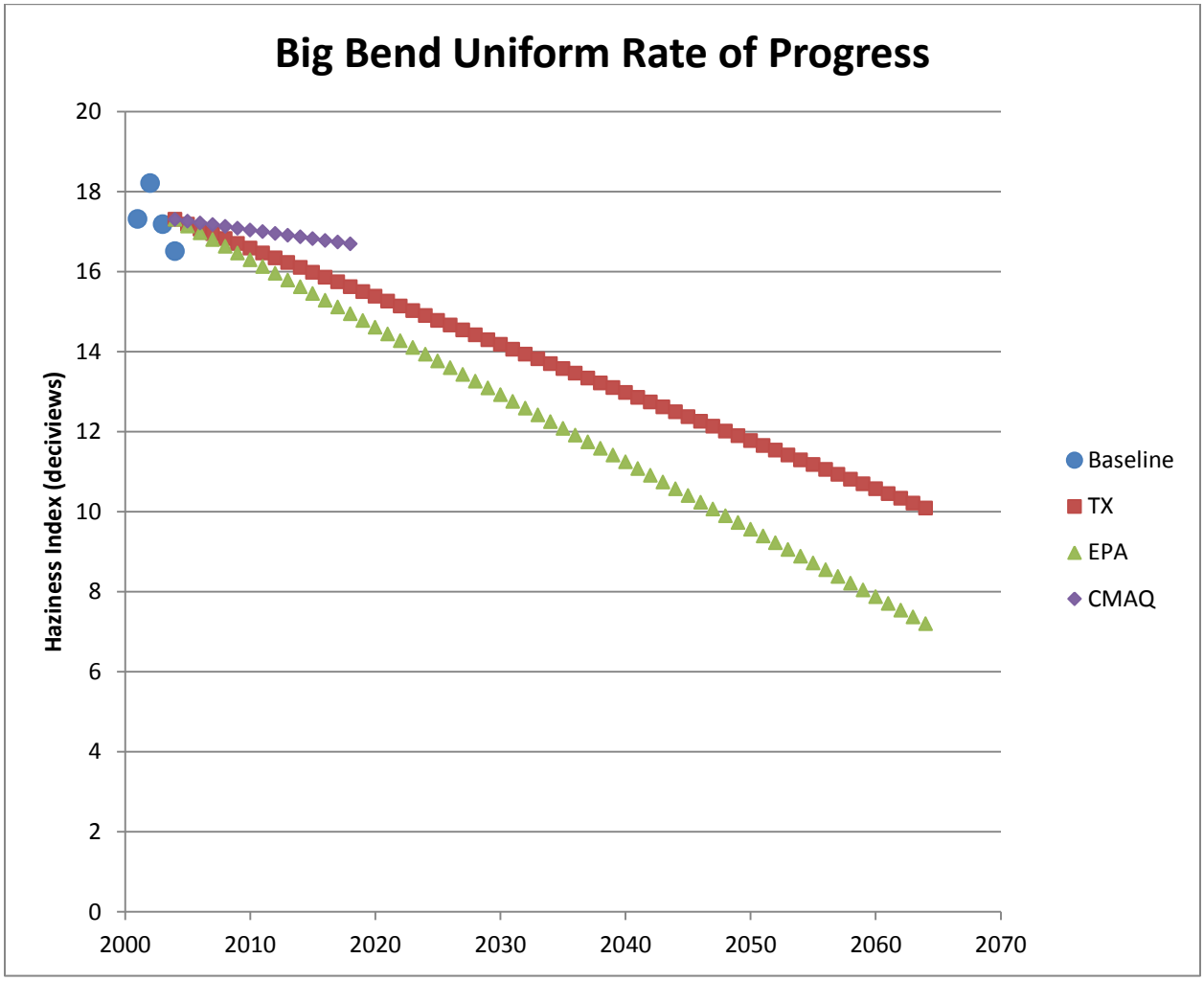
> The NPS, FWS, and FS acknowledged Texas' right to develop its own estimates of natural conditions, as established in 40 Code of Federal Regulations (CFR) 51.308; however, the FLMs requested that the EPA default estimates of natural conditions given equal weight in all tables, plots, and predictions that involve or depend upon an estimate of natural conditions.
>
> **The comparisons with the EPA default, or more specifically, the Natural Conditions II (NC II) committee's estimates using the New/Revised IMPROVE Algorithm, are available in Appendix 5-2. The commission made some changes in response to this comment, however the NC II estimates will remain in the appendix.**

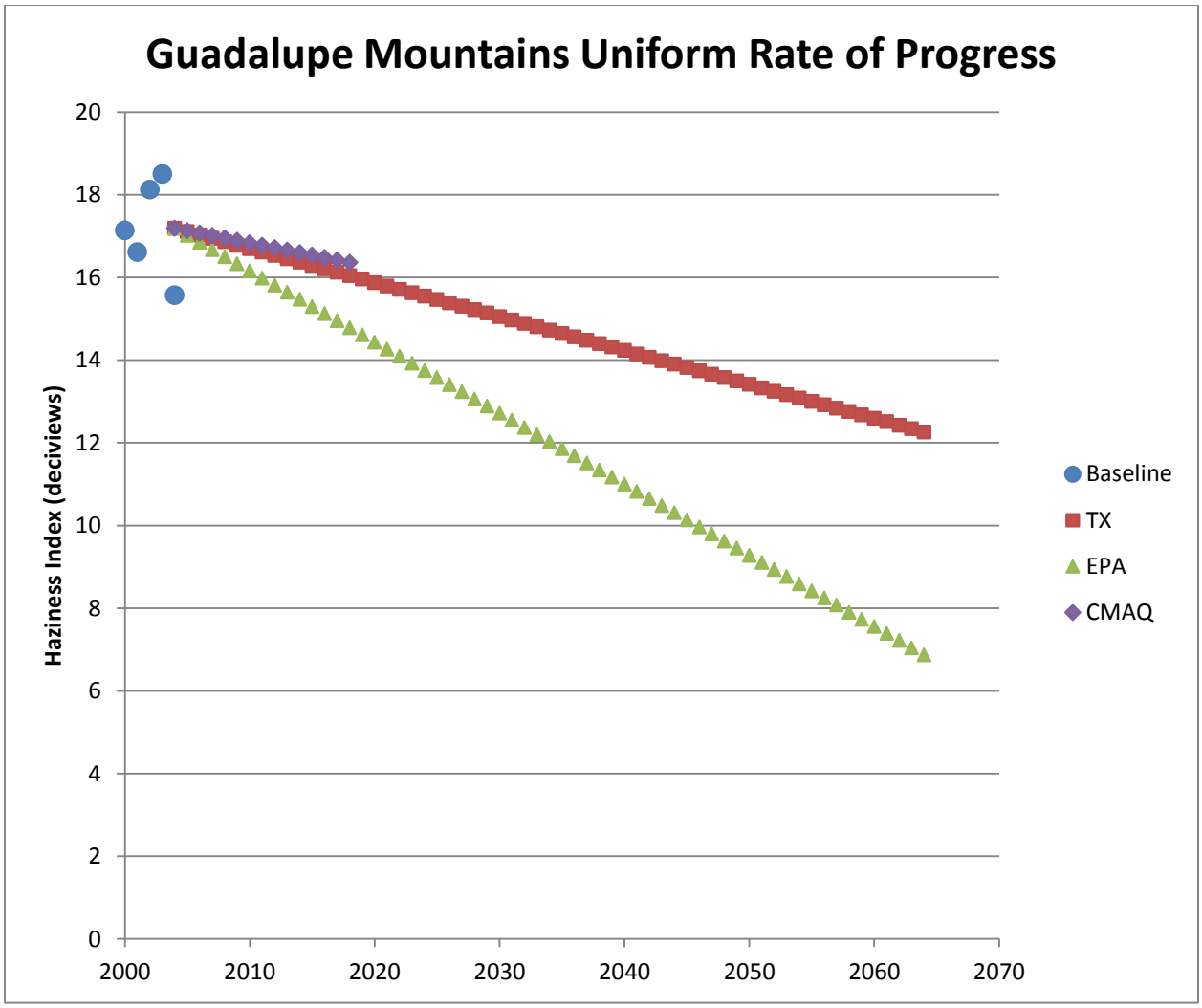
---

[2] **10.5 UNCERTAINTY IN THE REASONABLE PROGRESS GOALS**

[3] **CHAPTER 10. REASONABLE PROGRESS GOALS, 10.1 INTRODUCTION**

Because TCEQ declined to show the EPA default glidepath in the SIP main text or the Progress Report, we are providing that information for public review.






In its 2009 SIP submittal,[4] Texas noted that:

> Because natural visibility estimates are calculated from complex environmental chemistry, require significant assumptions in the calculation and are ultimately calculated without a directly observable measurement, there remains considerable potential for improvement in estimation. Since the natural concentrations and statistics of all components important for Regional Haze have significant uncertainties, the TCEQ will be continuing to evaluate data, modeling, and any other sources of information, as well as potentially devising additional monitoring, sampling and/or analysis schemes, in order to further improve these estimates. Furthermore, the TCEQ plans to work with the EPA, FLMs, and other experts and researchers to refine natural conditions estimates for future five-year reports and major regional haze SIP revisions.
>
> At this point, the component that most likely needs improved estimation is organic carbon.[5] Improved sampling and/or analysis techniques are likely methods in the pursuit of an improved characterization of the

[4] **5.4 NATURAL VISIBILITY CONDITIONS, AN ONGOING EFFORT**

[5] Additionally, there is significant regulatory uncertainty with regard to what prescribed fires should or should not be considered as "natural." When the EPA revises the *Interim Air Quality Policy on Wildland and Prescribed Fires*, it is expected such issues will be clarified.

> natural contributions to this component. However, the application of such methods will depend upon available resources and estimates of potential benefits.

There is no mention of any effort to improve these estimates of natural visibility conditions in the Progress Report.

In our January 2008 comments to Texas, we expressed our concern about Texas use of its "refined" default natural conditions while its neighboring states were using the EPA default:

> Therefore, we request that the Texas SIP specifically agree with its neighboring States' use of EPA-IMPROVE default natural conditions estimates for the neighboring States' Class I areas. In doing so, Texas would acknowledge that those States will be using EPA-IMPROVE calculations when addressing the possible need for additional controls on some Texas air pollution sources when setting reasonable progress goals for Class I areas outside of Texas. This is particularly important as it pertains to Carlsbad Caverns NP in New Mexico just northeast of Texas' Guadalupe Mountains NP, since these two Class I areas share the same IMPROVE monitor. Furthermore, in its evaluations of Texas sources' impacts to Class I areas located in other States, TCEQ needs to use the metric and approach that is selected by the State where each respective Class I area is located.

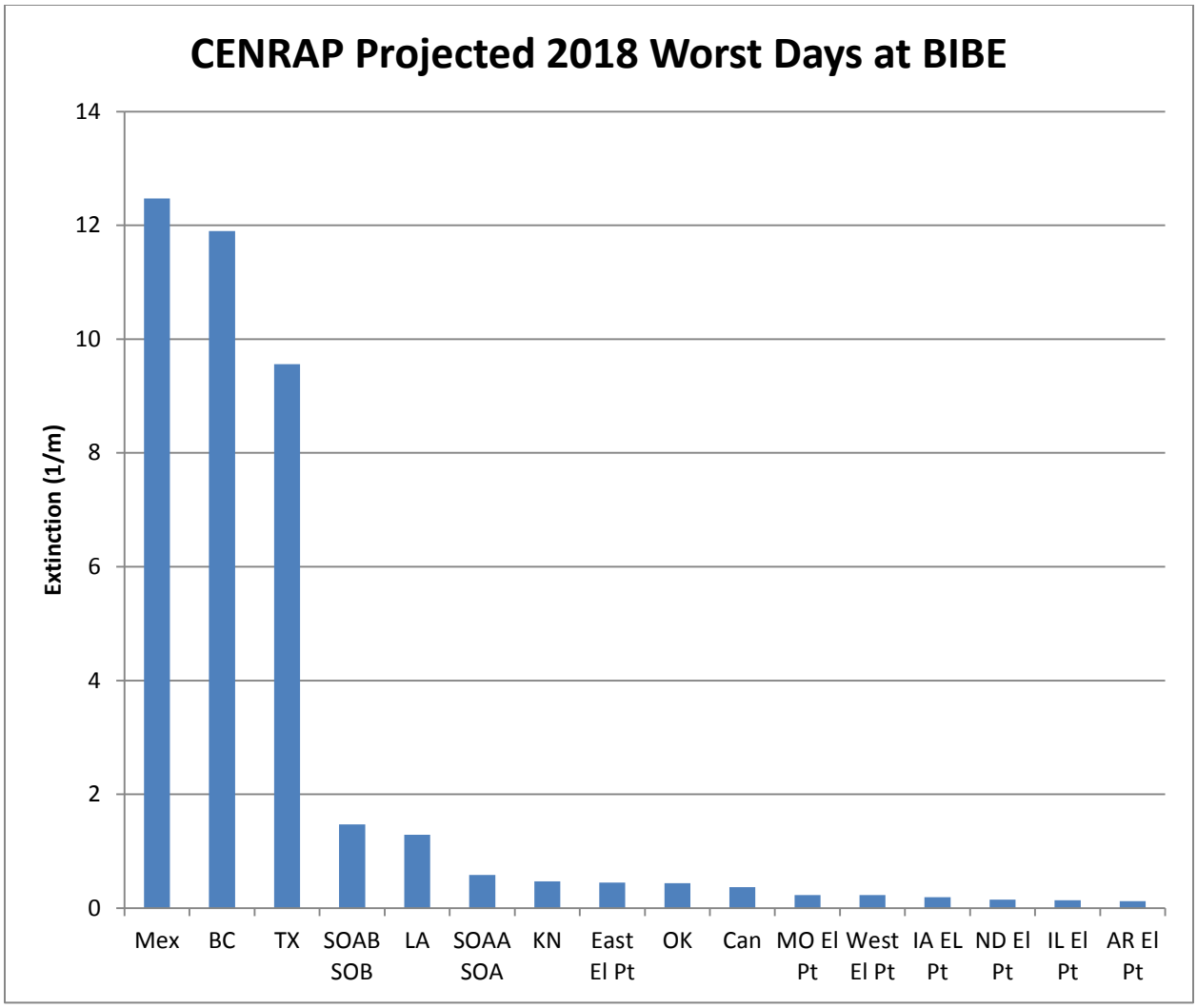
We again request that Texas respond to our concern.

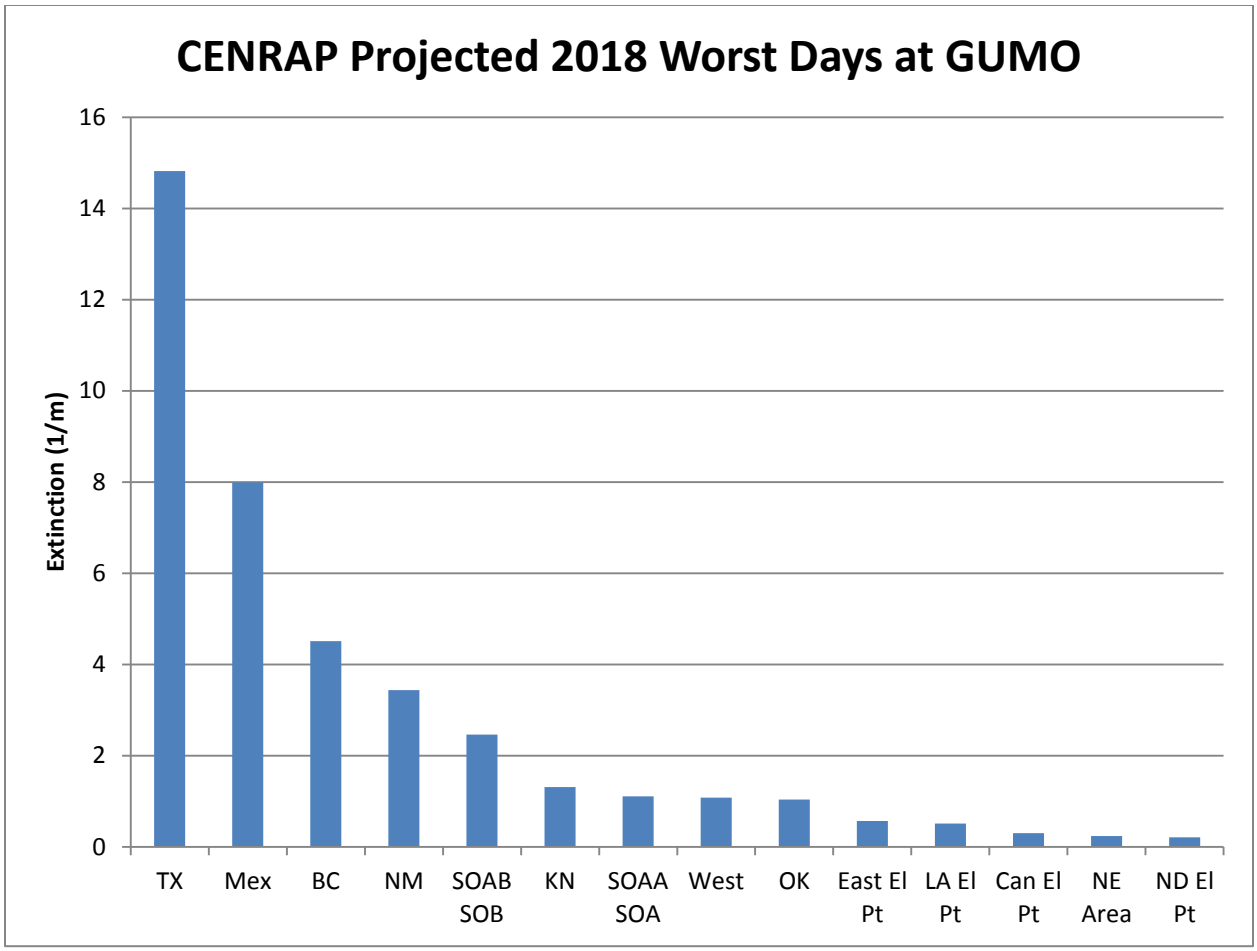
We have additional concerns that were not addressed in the Progress Report regarding SIP submittal section "**10.2 REASONABLE PROGRESS GOALS FOR TEXAS CLASS I AREAS"**

> The TCEQ has determined that the rate of visibility improvement by 2018, shown in Table 10-2: *Reasonable Progress Goals for Class I Areas (Worst 20 Percent Days)*, is reasonable and will be implemented as the RPGs for the listed Class I areas.

Table 10-2 in the 2008 SIP shows 0.7 dv improvement at BIBE and 0.9 dv improvement at GUMO by 2018. However, Appendix 8-1 of the TSD for CENRAP Emissions and Air Quality Modeling predicts 16.69 dv at BIBE and 16.35 dv at GUMO by 2018. (The 2008 SIP figures 10-1 and 10-2 truncate these 2018 estimates to 16.6 dv at BIBE and 16.3 dv at GUMO.) The resulting improvement is 0.61 dv (0.04 dv/yr) at BIBE and 0.83 dv (0.06 dv/yr) at GUMO by 2018.

Table 10-2 also projects that natural conditions will be achieved in 151 years at BIBE and 77 years at GUMO. Even using the Texas' estimates for natural conditions, those natural conditions would not be achieved for 165 years at BIBE and 83 years at GUMO. Use of the EPA default natural conditions means that natural conditions would not be achieved for 231 years at BIBE and 174 years at GUMO.


CENRAP Projected 2018 Worst Days at BIBE
Extinction (1/m)
14
12
10
8
6
4
2
0
Mex
BC
TX
SOAB SOB
LA
SOAA SOA
KN
East El Pt
OK
Can
MO El Pt
West El Pt
IA EL Pt
ND El Pt
IL El Pt
AR El Pt




It is clear from these charts that Texas contributes more to visibility impairment at these national parks than any other state.

# EXHIBIT 17

# United States Department of the Interior

OFFICE OF THE SECRETARY
Washington, D.C. 20240

JAN 11 2008

In Reply Refer To:
FWS/ANRS-NR/034492

Glenn Shankle, Executive Director
Texas Commission
on Environmental Quality
Mail Code 109
Post Office Box 13087
Austin, Texas 78711-3087

Dear Mr. Shankle:

On November 16, 2007, the State of Texas submitted a proposed State implementation plan (SIP) describing its proposal to improve air quality regional haze impacts at mandatory Class I areas across your region (reference TCEQ project number 2007-016-SIP-NR). Technical appendixes that are referenced in the SIP were received from the State on November 26, 2007. The Fish and Wildlife Service (FWS) and National Park Service (NPS) received and have conducted substantive review of your draft Regional Haze Rule implementation plan, prepared in fulfillment of your requirements under regulations 40 CFR 51.308(i)(2).

We appreciate the opportunity to work closely with the State through the initial evaluation, development, and review process of this plan. Please note that only the Environmental Protection Agency (EPA) can make a final determination regarding the document's completeness and therefore its ability to receive Federal approval from EPA.

As outlined in a letter to each State dated August 1, 2006, our review focused on eight basic content areas, which reflect priorities for the Federal Land Management agencies. We have enclosed comments associated with each of these content areas. In general, our review of the State of Texas draft plan indicates a need to more completely address the land management agency priorities. We request that further consultation take place with this prior to final adoption of the Texas Regional Haze Plan. The FWS and NPS air quality staffs stand ready to work with you towards resolution of these issues. We look forward to your response, as per section 40 CFR 51.308(i) (3). Specific questions regarding the review of and consultation on the draft plan may be directed to Mr. Tim Allen, Fish and Wildlife Service Branch of Air Quality, at (303) 914-3802, or Bruce Polkowsky (NPS) at (303) 987-6944.

Again, we appreciate the opportunity to work closely with the State of Texas and compliment you on your hard work and dedication to significant improvement in our Nation's air quality values and visibility. Cooperative efforts such as these ensure that, together, we will continue to make progress toward the Clean Air Act's goal of natural visibility conditions at all of our most pristine National Parks and Wilderness Areas for future generations.

Sincerely,

Lyle Laverty

Lyle Laverty
Assistant Secretary for
Fish and Wildlife and Parks

Enclosure

**U.S. Fish and Wildlife Service and National Park Service Comments Regarding Texas Proposed Regional Haze Rule State Implementation Plan (TCEQ project number 2007-016-SIP-NR)**

On November 16, 2007, the State of Texas submitted a Proposed Regional Haze Rule State Implementation Plan (SIP), pursuant to the requirements codified in federal rule at 40 CFR 51.308(i)(2), to the U.S. Department of the Interior, U.S. Fish and Wildlife Service (FWS), and National Park Service (NPS). Technical appendixes that are referenced in the SIP were received from the State on November 26, 2007.

The air program staff of these Federal Land Management (FLM) agencies have conducted a substantive review of the Texas Proposed SIP, and provide the comments listed below. The comments which are highlighted in **bold face** discuss what we consider major shortcomings of the proposed SIP that we believe warrant additional consultation prior to final adoption of the Texas Regional Haze Plan.

We are providing these comments to the State and wish them to be placed in the official public record. We look forward to your response as per section 40 CFR 51.308(i)(3), and are prepared to work with the Texas Commission on Environmental Quality (TCEQ) staff towards resolving the major issues discussed below. For further information, please contact Tim Allen (FWS) or Bruce Polkowsky (NPS) at (303) 914-3802 and (303) 987-6944, respectively.

## Overall Comments

*Attribution and Reasonable Progress Considerations – Class I Areas Outside of Texas*

**The reasonable progress analyses are missing specific information about Texas's contributions to visibility impairment at the Wichita Mountains Wilderness Area (FWS managed) in Oklahoma or other out-of-State Class I areas. Although the Proposed SIP references that the TCEQ consulted with Oklahoma at their request, the Texas Proposed SIP fails to document how emissions and impacts from Texas' sources were addressed. The FWS requests that an analysis based on an area of influence be developed and a full reasonable progress evaluation covering Texas' sources be established for the Wichita Mountains Wilderness Area. The same is needed for the Salt Creek Wilderness Area (FWS managed) and Carlsbad Caverns National Park (NPS managed) in New Mexico, as well as the Forest Service's Caney Creek Wilderness Area in Arkansas and White Mountains Wilderness Area in New Mexico.**

*Attribution and Reasonable Progress Goals – Texas Class I Areas*

**In establishing reasonable progress goals, the State of Texas fails to establish a sufficient relationship between the most attributable sources for visibility impacts and the affected Class I areas. Throughout the document, it is difficult to ascertain what geographical source region and which sources contained within that region, TCEQ considered when establishing the total costs for visibility improvement at the two Class I National Parks within Texas. As such, there is insufficient response to the statutory four factor analysis to show that controls at specific sources on a cost per ton basis are**

**unreasonable. The NPS requests that TCEQ identify specific geographic regions, based upon area of influence studies, that encompass the most important visibility-affecting emission sources for Big Bend National Park (NP) and for Guadalupe Mountains NP (both NPS managed) and focus its reasonable progress analyses for these two in-State Class I areas on those geographic regions. Please identify significant point (Texas highlighted point sources as the primary control sources) sources in those areas-of influence and conduct a thorough reasonable progress analysis with more specific four-factor responses for that source region.**

*Uncertainty of CAIR implementation and ongoing PSD/NSR review*

**We are troubled by TCEQ's response to an apparent large uncertainty associated with implementation of the Clean Air Interstate Rule (CAIR) and ongoing Prevention of Significant Deterioration/New Source Review (PSD/NSR) permitting program efforts. Although the State identifies clear conflicts with emission inventories developed by CENRAP,[1] with the Integrated Planning Model (IPM) predictions of large electric generation utility growth results, and with the unwillingness of participating CAIR sources to commit to particular emission levels, it is extremely concerning that the State has elected to wait and see how the uncertainty unfolds as part of the required five-year review. Inaction due to uncertainty is not prudent public policy, since it places all risk on the visibility resource at the Class I areas and does not ensure reasonable progress as required by the Clean Air Act and EPA's regulations.**

**The federal Regional Haze rule mandates that each State develop a plan to make progress toward visibility impairment at Class I areas. Although TCEQ concludes that the already planned controls between now and 2018 are reasonable, it fails to address how multiple issues which prevent the State from accurately determining future emissions from specific sources will result in anything more than a toss of the dice with respect to addressing Texas' substantial contribution to visibility improvement at Class I areas inside and outside of its territory. At a very minimum, the FWS and NPS request that the State develop areas of influence and associated major source lists within these zones as a precursor to a focused five-year review. The State should also establish in the regional haze SIP a process for ongoing discussions and consultations with neighboring States and FLMs on the progress of CAIR and PSD/NSR efforts.**

*Recalculation of Natural Conditions*

**TCEQ elected to recalculate natural conditions for Big Bend NP and Guadalupe Mountains NP in western Texas. Although 40 CFR 51.308 gives the State that right, reestablishing the natural condition has a significant and profound effect on progress over the 10 year planning period and beyond. Considering the potential outcome of such a recalculation, the State also bears the responsibility to fully disclose the associated consequences for making such a decision.**

**The State should fully and clearly summarize the reasons, methods, and consequence of these calculations by providing sufficient information on how the State's**

---

[1] Central Regional Air Planning Association (CENRAP) is an organization of states, tribes, federal agencies and other interested parties that identifies regional haze and visibility issues and develops strategies to address them. CENRAP is one of the five Regional Planning Organizations (RPOs) across the U.S. and includes the states and tribal areas of Nebraska, Kansas, Oklahoma, Texas, Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

**progress would display given the Environmental Protection Agency (EPA) default natural values. At key locations in the Proposed SIP, TCEQ suggests projections of progress using the EPA defaults are available in an appendix. It is important for the State to summarize these results using EPA defaults and present them side by side with the State's modified values within the main body of the SIP narrative.**

The remaining comments provided below are organized according to the priorities that we presented in our August 1, 2006, letter. Many of the following comments will provide additional direction towards building the narrative of the Proposed SIP to satisfy the overall concerns noted above.

**Baseline, Natural Conditions, Uniform Rate**

1. On page 5-3 of the Proposed SIP, Section 5.3 discusses the State's use of revised natural conditions estimates for the most and least impaired days at Big Bend NP and Guadalupe Mountains NP. We have reviewed Appendix 5.2 and find that the basic approach used to adjust natural conditions is reasonable, provided that the Proposed SIP address the uncertainty of the assumption that all of the coarse mass and fine soil fraction on the worst 20 percent days is natural. **Since there is human activity in the region, the State should provide a rationale for what fraction of soil and coarse mass is natural, and present an alternative where that fraction of the coarse mass and fine soil concentrations are assumed to be natural within the SIP narrative. In addition, we request that the SIP narrative include the default EPA predictions of natural conditions so that the reader can better understand the scope of changes Texas has chosen to make and can judge the effect of the State's choice on efforts to assess reasonable progress later in the SIP. Default values of natural conditions should be included in Table 5-2.** It would also help the reader to summarize how the refinement affects the revised natural condition if the State included a chart showing the breakdown of each basic pollutant component. This would give a non-technical reader a simple reference about which components in the haze calculation were changed and by how much.

2. Both the SIP narrative (Section 5.1.1) and Appendix 5-2 (Section 5.1) explain the 40 CFR 51.308(d)(2)(iii) provision that affords each state the ultimate responsibility for calculating natural conditions for Class I areas that are within that state. The SIP and appendix also explain that EPA guidance allows for states to derive "refined" estimates of natural conditions as an alternative to utilizing the "default" estimates. It is on these bases that Texas has chosen to pursue alternative methods for establishing natural conditions for Big Bend NP and Guadalupe Mountains NP, which are located within the State of Texas. However, on page ES-1, the Executive Summary to the SIP narrative states that, "The TCEQ used a refined estimate of natural conditions for Class I areas in Texas *and other states* as permitted by EPA guidance," (emphasis added). Based upon past discussions with Texas and neighboring States, we are unaware of any other States in the area that have chosen to adopting the alternative natural conditions calculation approaches that TCEQ has elected. **Therefore, we request that the Texas SIP specifically agree with its neighboring States' use of the EPA-IMPROVE default natural conditions estimates for the neighboring States' Class I areas. In doing so, Texas would acknowledge that those States will be**

**using EPA-IMPROVE calculations when addressing the possible need for additional controls on some Texas air pollution sources when setting reasonable progress goals for Class I areas outside of Texas. This is particularly important as it pertains to Carlsbad Caverns NP, in New Mexico just northeast of Texas' Guadalupe Mountains NP, since these two Class I areas share the same IMPROVE monitor. Furthermore, in its evaluations of Texas sources' impacts to Class I areas located in other States, TCEQ needs to use the metric and approach that is selected by the State where each respective Class I area is located.**

3. Section 5.2 of the Proposed SIP discusses baseline visibility conditions for the Big Bend NP and Guadalupe Mountains NP Class I areas, and references data provided on the "Visibility Information Exchange Web System" (VIEWS) that derives the baseline conditions. CIRA recently updated the calculations of baseline due to errors found in two different calculations. Please check with the VIEWS web site and verify that estimates used in the Proposed SIP are current.

4. Please note that within Appendix 5-1 the document makes reference to information available through an internet "ftp" website (see Section 5.2 of that appendix). The link that is provided is to a site that is password protected, and not publicly available.

**Emission Inventories**

5. Near the bottom of page 7-1 of the SIP narrative, the document states: "The $SO_2$ emissions modeled by the CENRAP are significantly higher than the 15,633 tons per year (TPY) reported by the TCEQ…." After searching both the SIP narrative and its appendices, we cannot determine whether this is referring to the total of all $SO_2$ emissions, or a specific category of emissions. The paragraph continues, saying, "CENRAP's modeled emissions estimate is not expected to significantly impact visibility estimates for 2018 because of the relatively small contribution from these Texas sources on Class I areas." However, figure 11-6 on page 11-5 of the SIP narrative suggests that Texas sources' emissions constitute the majority of visibility impact at the Wichita Mountains Wilderness Class I Area in Oklahoma. Figures 11-5 and 11-9 show similar results for the Salt Creek Wilderness Area (New Mexico) and Caney Creek Wilderness Area (Arkansas), respectively; and the data in Table 1 of Appendix 10-1 indicates that Texas sources' emissions have a great impact at the White Mountains Wilderness Area (New Mexico). **Please explain the specific difference between the reported TCEQ $SO_2$ inventory and the CENRAP modeled inventory that this paragraph attempts to address, as well as the rationale for why TCEQ considers Texas' contribution to visibility impairment in neighboring States' Class I Areas to not be significant.**

6. On page 7-2, Table 7-3 shows that emission estimates of organics, primary particulates and ammonia are predicted to increase during the planning period (years 2002 to 2018). The text references both Appendix 7-1 and the CENRAP technical support document. (Note that the text says that this CENRAP TSD is not included in with the SIP, directing the reader to the CENRAP website; however, Appendix 8-1 to the SIP is this CENRAP TSD.) While these supporting documents do contain discussions of the 2018-year emissions inventory

development, the specific supporting information is often difficult to locate, especially within the extensive CENRAP TSD. We suggest that TCEQ include a summary within the SIP narrative of why estimates predict increases in organics, primary particulates, ammonia, and area source $SO_2$, together with a discussion of how much these increases are expected to affect visibility impairment at both Texas' and neighboring States' Class I areas. This discussion should also consider the effects of emission decreases projected for sulfur and nitrogen products.

7. In Chapter 8, Figures 8-4 and 8-5 (on pages 8-15 and 8-16) are intended to support the discussion of model performance evaluation. Please explain why the tables are referencing the Typ02g base year inventory instead of the actual 2002 performance inventory.

8. Further, there is a considerable amount of discussion in the Proposed SIP stating that emissions used by CENRAP and others for modeling were greater than the inventory reported by TCEQ. But, Figures 8-4 and 8-5 utilize the CENRAP typical base year inventory of 2002, and consistently show significant under prediction of all visibility impact parameters when compared to observed values. Although the model is later used in a relative sense (employing relative reduction factors (RRFs)), it is important for the State to address this apparent discontinuity between text describing a significant over estimate of $SO_2$ emissions and model performance metrics that indicate a significant under estimate.

9. Section 8.4.17 states that off-shore emissions were held constant through the planning period. But, Figure 11-10 (page 11-8) showing predicted 2018 attribution to the worst 20 percent visibility days indicates that Gulf of Mexico contributions are significant. Many of the off-shore gas and oil development activities are under U.S. controlled permit programs. Please explain why these emissions were not grown into the future and accounted for consistent with other similar on-shore emissions.

10. Section 8.4.17 presents a discussion of relative response factors and the two methods of applying RRFs created by the CENRAP organization (beginning on page 8-17). We greatly appreciate your summary of these concepts being presented in the main body of the SIP. It is very important to inform the non-technical reader how these complex models are applied in a relative sense.

**Best Available Retrofit Technology (BART)[2]**

11. The overview of BART in the EXECUTIVE SUMMARY says, "...This SIP revision contains a list of BART-eligible sources and the determination of BART for each source that is reasonably anticipated to contribute to visibility impairment (BART-subject)." This

[2] BART-eligible sources are those sources that have the potential to emit 250 tons or more of a visibility-impairing air pollutant, were put in place or under construction between August 7, 1962 and August 7, 1977, and whose operations fall within one or more of 26 specifically listed source categories. Under CAA section 169A(b)(2)(A), BART is required for any BART-eligible source which "emits any air pollutant that may reasonably be anticipated to cause or contribute to any impairment of visibility in any such area."

statement is misleading, since in the SIP itself TCEQ finds that none of its sources is, "BART-subject," and thus there is no BART determination provided at all.

12. The Regional Haze rule establishes BART criteria for exempting sources that are determined to be non-significant. EPA offers an upper bound to that single source significance level at 0.5 dv. The State must provide a discussion or justification how it arrived at its selected threshold value. In the case of Texas, it appears that BART controls may have a cumulative affect on Class I area visibility and that a lower value than EPA's upper bound for BART exemption may have produced a noticeable difference. At a minimum, a lower threshold level could have provided the State with important specific source information on these sources.

13. It was difficult to verify the status of the 120 "BART-Eligible Sources Based on Results of TCEQ Survey" that are listed in Table 9-1 of the Proposed SIP narrative. The following discussion outlines our understanding of the disposition of these 120 "BART-eligibles." Please verify this interpretation.

    Section 9.2 of the Proposed SIP narrative explains the options and provides lists of sources that exempted through CAMx screening (72 sources, listed in Table 9-2), CALPUFF individual source modeling (29 sources listed in Table 9-3), and CAMx individual source modeling (6 sources listed in Table 9-4). This accounts for 107 of the 120 BART-eligible sources. But, Section 9.3 immediately follows, stating: "Upon conclusion of all BART screening analyses, no Texas sources remained subject to BART."

    The paragraph just above Section 9.2.1 (on page 9-5 of the Proposed SIP) ends saying: "BART-eligible sources that did not screen out in any of the modeling analyses had the option of reducing the emissions from their BART-eligible units using an enforceable mechanism, such as a permit, or performing an engineering analysis. The BART-eligible sources that chose to reduce potential emissions are discussed in Section 9.4. The emission reductions resulting from the engineering analyses and resulting emission controls are presented in Section 9.5." (Note that the cited passage indicates that emissions reductions from these facilities are presented in Section 9.5; however, Section 9.5 moves on to a different topic.)

    Table 9-6 in Section 9.4 lists the sources that chose to reduce emissions (page 9-11). There are nine facilities listed here. However, one of these (EXXONMOBIL OIL, account # JE0067I) also appears on the list of sources exempted through individual CALPUFF modeling in Table 9-3. So, there are eight additional sources accounted for, yielding a total of 115 of the original list of 120 BART-eligibles in Table 9-1.

    Section 9.5 and Table 9-7 provides a list of 22 sites that, "requested removal from further BART consideration per the exemptions in the [January 10, 2007, TCEQ BART] rule or based on updated information on the site." Among this list are the five remaining facilities from the original list, plus seven of the nine facilities listed in Section 9.4 (Table 9-6), two of the facilities identified in Section 9.2.1 (Table 9-2), and eight additional facilities that were not part of the original list of 120 BART-eligible sources.

    We understand that the "exemption list" of Section 9.5/Table 9-7 is broader than the original survey of BART-eligible sources (Table 9-1), and that it was derived some five years later after the finalization of TCEQ's BART rule.

14. The two tables in Section 9.2.2 "Individual Source Attribution Approach," identify the BART-Eligible sources that were exempted after performing source-specific BART engineering determinations through either CALPUFF modeling (Table 9-3) or CAMx modeling (Table 9-4). It would be helpful to list the modeled visibility impact results for each of these facilities in these tables (i.e., Class I area(s), deciview impact(s) and distance/direction information for each Class I area evaluated in the individual source modeling analyses). This information would provide the reader with a quick reference of the relative importance of each listed facility that was exempted through individual source attribution modeling. In addition, those BART-eligible sources that have impacts near the BART exemption threshold applied by TCEQ would form a basis for reasonable progress evaluations for affected Class I areas.

15. Table 9-6 of the Proposed SIP (page 9-11) identifies nine facilities that reduced a total of 9,488 tons per year of visibility impairing pollutants ($NO_X$, $SO_2$, and $PM_{10}$) through voluntary potential-to-emit emission reductions. The Proposed SIP references "Appendix 9-10: *Documentation of Emission Reductions,"* as providing the supporting information for this table. Within that appendix, there is a table labeled "Table 9-11.1 Changes in Emissions" (see fifth page of the electronic file APP9_10.PDF). The data in the appendix table cites a total reduction of visibility impairing pollutants of approximately 18,650 tons per year. The primary difference is the amounts listed for ExxonMobile Oil (JE0067I). The first table (Table 9-6 of the Proposed SIP) footnotes this source, saying "ExxonMobil numbers are preliminary and subject to change…." We understand that this facility's emissions estimate is dependent upon the outcome of a national consent decree. It is important that the emission rates used by the facility to become exempt from BART control technology requirements (whether through source-specific exemption modeling or reducing emissions to qualify for removal from further consideration under the TCEQ BART rule) are in fact realized by the BART-eligible units at this facility. Please reconcile the differences between the two tables and provide more definite information regarding the ExxonMobil facility.

**Area of Influence**

16. As stated in the letter from the NPS and FWS dated August, 2006, subdividing a geographic area in order to place emphasis on sources that have the highest potential to provide benefit to reducing visibility impairment is important. In large geographic states such as Texas or Alaska, establishing these areas of influence (AOI) are very important for describing appropriate cost benefit arguments, since evaluations applied on a state-wide basis are often not relevant for any specific Class I area. We ask that such areas be clearly identified by some geographic means, and to encompass sources that have the most visibility impairing significance for a given Class I area. In the case of Texas, CENRAP has already generated AOI information. Samples that include geographic extent and significant source information were included by the State of Oklahoma as part of the briefing package for its consultation calls. Although those examples are specific to Wichita Mountains, AOIs were produced for all CENRAP Class I areas. **Since existing and predicted future visibility impairment at many nearby Class I areas outside of Texas is more attributable to Texas' emissions than those of the host States, it is also important to confer with the host States when**

**generating and refining these AOIs and when interpreting whether controls at specific contributing sources are cost beneficial.**

17. The NPS and FWS request that TCEQ develop and adopt an AOI approach to best define cost benefit information when concluding reasonable progress factors. Class I sites that should be included, in addition to the two National Park Class I areas located in Texas, are the following Wilderness Areas: Salt Creek (FWS managed, in New Mexico), Wichita Mountains (FWS managed, in Oklahoma), Caney Creek (Forest Service managed, in Arkansas), and White Mountains (Forest Service managed, in New Mexico).

**Reasonable Progress Goals; Long Term Strategy**

18. Section 10.2 of the Proposed SIP presents TCEQ's Reasonable Progress Goals for the two Class I areas located within the State. Earlier in this enclosure, we commented regarding TCEQ's refined estimates for natural conditions at these Class I areas. **Just as we requested that the SIP also include the default values established by EPA for comparison, we ask that the Reasonable Progress discussion in Section 10.2 also present for comparison the glide path and 2018-year reasonable progress goals reflecting the default EPA-based estimates of natural condition.**

19. **On page 10-2, Section 10.2 of the Proposed SIP states that Appendix 10-1 provides an analysis of the four factors identified by statute as required for setting reasonable progress goals, and concludes that based upon these factors the goals are reasonable. The information in that appendix should be summarized in the main body of the SIP and should clearly state the decision of the State on a Class I basis. In addition, please note that this appendix, as well as most of the appendices for the Proposed SIP, is only "available upon request" at the TCEQ's website. Since significant portions of the rationale for TCEQ's Proposed Regional Haze SIP are contained within the appendices, these should be posted for public examination along with the SIP narrative document.**

20. **Appendix 10-1 presents information for Texas' reasonable progress controls and the four factors analysis. This summary is a required element in the Regional Haze rule and should be included in the main body of the SIP. Additional references cited in the reasonable progress discussion, including the Alpine Geophysics, CENRAP, and EPA works should be included for review as appendices. Although the narrative portion of Appendix 10-1 presents an argument to conclude that additional controls are not reasonable, supporting information on how the controls were tested is neither provided nor described. Tables 6 through 10 of the appendix appear to include information that is not relevant to the narrative description. The tables include information on sources likely to impair visibility at Class I areas other that Guadalupe Mountains NP and Big Bend NP, yet present cost estimates that are in the ball-park of those quoted in the narrative. No narrative information is provided regarding cost benefit of controlling sources that may impair Class I areas outside Texas.**

    **Please present information on how the controls were analyzed and provide tables specific to each Class I area. Please include analysis for all Class I areas to which Texas contributes.**

21. The beginning discussion of Appendix 10-1 identifies the Class I areas for which emissions originating in Texas contribute 20 percent or more to visibility impairment. The basis for the 20 percent cutoff is unclear. Following the initial discussion of the pollutants and broad source categories of concern, the rest of this Appendix uses only the two in-State Class I areas to determine whether any additional controls would be reasonable and ignores the reasonable progress goals and potential visibility improvement at Class I areas in other states.

    Chapter 10 of the SIP should directly address apportionment of impacts from Texas' sources to Class I areas outside the borders of Texas, and measures that Texas will pursue to address these impacts. This seems particularly lacking with respect to the Wichita Mountains Wilderness Area. As outlined elsewhere in the Proposed SIP, apportionment from the PSAT modeling exercises show more contribution from Texas' sources than from those in Oklahoma. During the Oklahoma consultation conference call, the State of Oklahoma identified source regions shown through modeling to significantly contribute to visibility impairment at Wichita Mountains. For both $SO_2$ and $NO_X$, the identified source regions extend well into the State of Texas.

    Please provide a justification for the 20 percent contribution cutoff that TCEQ has used, as well as detailed information on how the State of Texas has evaluated reasonable control levels for its sources that impact Class I areas in other States. At a minimum, this should include the Wichita Mountains, Salt Creek, Caney Creek, White Mountain, and Carlsbad Caverns Class I areas.

22. Section 10.3 discusses the CAIR program's interaction with the Regional Haze plan. The uncertainty of CAIR controls is made quite clear in Texas with regard to purchased emission credits and source unwillingness to make control commitments. This level of uncertainty can have a heavy influence on the ability of the State to predict or meet visibility goals into the future. This is especially significant within a State that is as large as Texas. The appearance of a net reduction of emissions due to CAIR may still result in an overall increase of emissions within an area of influence surrounding a specific Class I area. Yet, the State manages this uncertainty by stepping back and waiting five years for the first SIP review. This approach, although quite respectful of CAIR, appears flawed in light of the information already received by the State.

    Significant visibility impacts on many Class I areas inside and outside Texas due to impacts from Texas sources, as demonstrated in the various CENRAP Class I area source apportionment and Area of Influence studies, will continue to be observed, even after implementation of CAIR and other already-enacted programs outlined in the Proposed SIP. Therefore, it is important to determine specific initiatives beyond BART and CAIR that might be considered for the period before the 2013 interim review and the 2018 regional haze SIP update are required. **At a very minimum, TCEQ should identify areas of influence for each Class I area and develop a list of the significant point sources within that area to form the primary basis to better evaluate the progress of those sources within the CAIR framework.**

23. On page 10-5, Section 10.4 discusses international sources of visibility impairment at the two Texas Class I areas. Table 10.7 presents data from the CENRAP PSAT modeling analysis which tracked contributions from many geographic areas to the sulfate and nitrate

components of extinction. These assessments do not necessarily reflect the contribution for other aerosols. Thus, Texas should clarify whether Table 10-7 is referring to total contribution to extinction or contributions to sulfate and nitrate impairment based on the CENRAP tracking model.

24. In addition, the text associated with Table 10-7 implies that the boundary conditions contribution to impairment is primarily from Central America. The CENRAP modeling assessment did not differentiate among five large-scale model boundaries when compiling data for sulfates and nitrates. It is also important for TCEQ to acknowledge that a portion of boundary conditions may be a result of recirculation of Texas and other U.S.-generated emissions. The Proposed SIP should note that boundary conditions are highly uncertain and that contributions from *within* the model boundaries may be significantly higher.

25. We agree that Mexico emissions contained within the boundaries of the CENRAP modeling domain are important contributors to visibility impairment at Big Bend NP and Guadalupe Mountains NP. We request that Texas acknowledge the work contained in the final Big Bend Regional Aerosol and Visibility Observational (BRAVO) study. The report and supporting data can be found at http://www2.nature.nps.gov/air/studies/bravo/index.cfm. This extensive BRAVO field study indicates that sources in Mexico, Texas and the eastern U.S. all play a role in sulfate conditions at Big Bend NP. We look forward to working with Texas to solicit EPA action with its sister agencies to address the Mexico portion of sulfate impairment at Big Bend. We also request that the Proposed SIP speak to the Texas contribution to sulfate found in the BRAVO field study in the Long Term Strategy and reasonable progress sections.

26. A November 16, 2007, cover memo from the TCEQ Chief Engineer to the Commissioners, outlines a "potentially controversial matter" under discussion between TCEQ, neighboring States, and the FLMs, regarding notification and opportunity to participate in new/modified Texas source permitting actions that may affect air quality related values, including visibility, at Class I areas. Some months ago, we learned that Texas was providing notification only for major-source actions within 100 km of Class I areas. The Proposed SIP and its supporting documentation show that haze-causing pollutants transport and have impacts at much greater distances. We have formally asked that the FLM agencies be notified of actions out to 300 km from our Class I areas, and Oklahoma sent a letter requesting similar consideration. The cover memo indicates that "[TCEQ} plans to work directly with the FLMs to try to resolve their concerns… [and] committed to keep Oklahoma informed of those discussions….]" We eagerly await continued dialogue to resolve this matter.

    The only place that New Source Review/Prevention of Significant Deterioration (NSR/PSD) permitting is addressed in the Proposed SIP is in Section 11.6.3. This Section outlines that Best Available Control Technology requirements already included in the Texas regulations will apply to all emissions increases at new or modified units. This discussion, however, does not indicate that the new or modified sources will need to evaluate their emissions' impacts to Class I area visibility. Please elaborate on how the NSR/PSD permitting programs will be utilized by TCEQ as part of its Long Term Strategy for meeting Reasonable Progress Goals.

27. At TCEQ's request, the CENRAP PSAT source apportionment modeling divided Texas into three regions: East Texas, TX Gulf Coast, and West Texas. Figures 11-4 and 11-7 of the Proposed SIP present impacts of only West Texas emissions on visibility impairment for Class I areas in New Mexico and Colorado, respectively. These graphics are misleading regarding the total impact of sources across Texas to these out-of-State Class I areas. For instance, Figure 11-5 shows that sulfate impacts at the Salt Creek Wilderness from sources in the East Texas are nearly the same as those from West Texas. Throughout the Proposed SIP, representation of impacts from Texas' sources should show and acknowledge contributions across the entire state.

**Fire**

28. Section 11.4.4 of the Proposed SIP discusses fire and smoke management issues in Texas as they relate to the Regional Haze SIP. This Section identifies Appendix 11-1 as containing several specific fire management plans and other such documents. Please note, however, that the CD that transmitted the electronic copy of the appendices contains only an empty folder labeled Appendix 11-1.

    That said, we recommend that TCEQ reference the fire and smoke management plans in a way that does not require SIP updates each time a fire/smoke plan is updated. Depending upon Texas' administrative procedures, this may indicate that the documents should not be contained in the appendix, but rather referenced as "living documents" and summarized in the SIP.

29. Please indicate whether Texas intends to "certify" its Smoke Management System as provided for by the 1998 EPA Interim Air Quality Policy on Wildland and Prescribed Fire.

30. The Proposed SIP and the smoke management plans described in its Section 11.4.4 should identify appropriate nearby Class I areas (both the two within Texas as well as those located in neighboring States) as smoke sensitive areas and prescribed burners should be required to apply the appropriate smoke management techniques to minimize smoke impacts.

31. The Proposed SIP states that wildfire emissions are assumed to remain the same looking forward over the ten-year planning period. However, the SIP should identify if prescribed burning emissions are proposed to decline, stay the same, or increase.

32. It is appropriate to declare smoke plans as a contributing program for visibility protection, but neither the State or RPO evaluated performance resulting from this or any specific smoke management component. If the State wants to speak to not making a change to the SMP, it should simply state that it is unreasonable to make modifications due to the low smoke apportionment or low priority of pollutant selection.

**Regional Consistency**

33. Because the components of haze transport over great distances, attribution and controls must be considered at a multi-State level. The State's Proposed SIP clearly indicates that attribution from Texas emissions, in whole or part (since Texas was subdivided into three

PSAT areas for modeling), not only contribute to visibility impairment at Class I areas outside the Texas boundary, but in fact these Texas emissions are clearly contributing at levels greater than those of the host State. This seems quite apparent at the Salt Creek, Wichita Mountains, White Mountains, and Caney Creek Wilderness Areas. **As such, we have a great expectation that the State of Texas will not only demonstrate progress towards visibility goals in these out-of-State Class I areas (as part of the Texas plan's reasonable progress discussion), but also show a great deal of effort in consulting and planning with these neighboring States. This expectation is quite analogous to Texas asking EPA to better control international emissions in order to make progress in Texas. The States of New Mexico, Oklahoma and Arkansas receive even larger percentages of total attribution to visibility impairment at their Class I areas from Texas sources than Texas' Class I areas receive from international sources.**

**The State of Texas should provide additional documentation and summaries on efforts to not only discuss impacts, but ways that the States planned to work together to make progress in Class I areas where Texas is the majority contributor. In other words, because the State is not only a contributor, but the majority contributor, additional efforts should be shown to demonstrate multi-State controls. This should be further extended to demonstrate consistent control levels.**

**Verification & Contingencies**

34. Chapter 6 of the Proposed SIP discusses the ongoing and future monitoring strategy for measuring visibility parameters and progress at the Class I areas within Texas. Section 6.1 identifies the Regional Haze Rule regulatory requirement of 40 CFR §51.308(d)(4) for a monitoring strategy to measure, characterize, and report regional haze visibility impairment representative of all mandatory Class I areas. TCEQ explains that this is accomplished through the IMPROVE monitoring network, and states that it will, "continue to participate in the [IMPROVE] network through the financial support of the EPA… [and also] through its membership in the CENRAP as long as the EPA continues to fund the CENRAP adequately." While we recognize that to date the IMPROVE network has been funded mostly through federal monies, it is important to note that the responsibility described at 40 CFR §51.308(d)(4) rests with the State, so that it can assess ongoing progress towards reaching the goals set in this SIP, as well as for inform future SIP revision and planning activities required under the national Regional Haze Rule. We share your interest with maintaining the IMPROVE network, and we are aware that there is a degree of uncertainness regarding the future of any individual monitoring site. The SIP should address the representativeness of both primary and alternative data sites, and also provide a more specific plan for ensuring that monitoring is continued regardless if national funding is not available.

35. Section 6.1 describes the current funding for the IMPROVE network to be primarily EPA with some funding from NPS. Please note that all the FLM agencies with Class I area management responsibilities (including FWS and FS) contribute to the establishment and operation of the IMPROVE monitoring network.

36. Furthermore, in Section 6-4, the Proposed SIP states: "If Texas collects any visibility monitoring data through the state's air quality monitoring networks, the TCEQ will report

those data to the EPA as specified under the Performance partnership Grant agreement…." Please clarify whether TCEQ has plans for additional visibility monitoring strategies, either as a supplement to the IMPROVE network, or for the possible outcome should the IMPROVE network become unable to fully supply information at some point in the future.

**Coordination & Consultation**

37. In both Sections 4.3 and 11.2, the Proposed SIP states that Arkansas and Missouri have accepted the Texas emission plan regarding their respective Class I areas, and that Texas was invited to and participated in consultation calls with Oklahoma regarding the Wichita Mountains Wilderness Area. However, the portion of the Proposed SIP that discusses the Oklahoma consultations fails to explain any issues that were discussed or conclusions that were reached regarding Texas sources' contribution to visibility impairment at Wichita Mountains. Rather, it simply suggests that Texas joined the consultation conference call. The Proposed SIP needs to fully explain the pertinent issues discussed and agreements reached through consultation activities to address all Class I areas where Texas' emissions are important contributors to visibility impairment, and not just the two Class I areas located within Texas.

38. The two Sections referenced above also indicate that there has been some communication with other States (specifically identifying New Mexico, Louisiana, and Colorado), but that no formal consultation has occurred with Texas regarding Class I areas located in these States. Although these states have not invited Texas to formal participation in their consultation process, this is, in some cases, simply a function of those States' timing, and not an implicit acceptance of Texas' long term strategy. Regardless of whether a neighboring State has initiated formal consultation, it is still important that the Proposed SIP address Texas sources' impacts on Class I areas located in those other States. Chapter 11 of the Proposed SIP presents information regarding apportionment of haze-causing pollutants, including Texas' emissions. However, the Proposed SIP is silent about reasonable controls for sources that have large impacts at outside-Texas Class I areas.

# EXHIBIT 18

# Technical Support Document for Demonstration of the Transport Rule as a BART Alternative

**U.S. Environmental Protection Agency**
**Office of Air Quality Planning and Standards**
**Research Triangle Park, NC 27711**
**December 2011**

**Docket Number EPA-HQ-OAR-2011-0729**

## Table of Contents

1.0 Introduction…… ……2
2.0 Emission Projections Used for Transport Rule Is Better-than-BART Analysis……..3
2.1 Eligible BART Units and Modeling Criteria…….…….……....4
2.2 Emission Projections……...9
3.0 Air Quality Modeling to Determine Future Visibility…….…..12
3.1 Overview of the Modeling Process……....12
3.2 Overview of the Future Year Visibility Projections……..13
3.3 Calculation of Base Year (Current) Visibility Levels…….....15
3.4 Projection of Future Year Visibility Level…….……20
3.5 Details of the Visibility Projection Methodology…….....21
3.6 Modeling Analysis of the Better than BART Two Pronged Test…….23
3.6.1 Better than BART Test- 1st Prong……..……...24
3.6.2 Better than BART Test - 2nd Prong……..……..…33
3.6.3 Summary of Better than BART Test……..…….41

Appendix A EGUs that were assumed to BART-subject for the purpose of this analysis……..…….…....42

Appendix B Analysis of Visibility Degradation at Four Class I Areas…….……55

Appendix C Sensitivity Analysis Accounting for Proposed Increases in Certain Transport Rule State Budgets……..…….61

## 1.0 Introduction

This Technical Support Document (TSD) provides details on the air quality modeling analysis performed in support of EPA's proposed determination that the trading programs in the Transport Rule[1], also known as the Cross-State Air Pollution Rule, achieve greater reasonable progress towards the national goal of achieving natural visibility conditions in Class I areas than source-specific Best Available Retrofit Technology (BART) in those states covered by the Transport Rule.

The Transport Rule requires 28 states in the eastern half of the United States to reduce electric generating unit (EGU) sulfur dioxide ($SO_2$) and nitrogen dioxide ($NO_X$) emissions that cross state lines and contribute to ground-level ozone and/or fine particle pollution in downwind states. BART, on the other hand, is applicable nationwide and covers 26 industrial categories, including EGUs of a certain vintage. The analysis described in this TSD sought to determine whether the Transport Rule air quality assured allowance trading program for EGUs will achieve greater visibility improvement than would BART for EGUs only.

Criteria for determining if a BART alternative (such as the Transport Rule trading programs) achieves greater reasonable progress than source-specific BART are set out in the Regional Haze Rule at § 51.308(e)(3). The "better-than-BART" test may be satisfied as follows: If the distribution of emissions is not substantially different than under BART, and the alternative measure results in greater emission reductions, then the alternative measure may be deemed to achieve greater reasonable progress. If the distribution of emissions is significantly different under the alternative, then an air quality modeling study is conducted to determine differences in visibility between BART and the alternative program for each affected Class I area for the worst and best 20 percent of days. The two-pronged visibility test would demonstrate "greater reasonable progress" under the alternative program if both of the following criteria are met:

- Visibility does not decline in any Class I area[2], and
- There is an overall improvement in visibility, determined by comparing the average differences between BART and the alternative over all affected Class I areas.

[1] See Federal Implementation Plans to Reduce Interstate Transport of Fine Particulate Matter and Ozone, 76 FR 48208 (August 8, 2011) and Federal Implementation Plans for Iowa, Kansas, Michigan, Missouri, Oklahoma, and Wisconsin To Reduce Interstate Transport of Ozone, 76 FR 40662 (July 11, 2011) for more details. For the purposes of the proposed Transport Rule is Better-than-BART rule and for the analysis described in this TSD, the Transport Rule includes all of the states (28) included in the final Transport Rule and the supplemental notice.

[2] The "decline" is relative to modeled future base case visibility conditions in the absence of any BART or alternative program control requirements (including CAIR and the Transport Rule).

The underlying purpose of both prongs of the test is to assess whether visibility conditions at Class I areas would be better with the alternative program in place than they would without it. The first prong ensures that the alternative program will not cause a decline in visibility at any affected Class I area. It addresses the possibility that the alternative program might cause local changes in emissions that could result in localized visibility degradation. The second prong ensures that the program results in improvements in average visibility across all affected Class I areas as compared to adopting source-specific BART. Together, these tests ensure that the alternative program provides for greater visibility improvement than would source-specific BART.

Since the distribution of emissions under the Transport Rule programs is substantially different than the distribution of emissions that might result from source-specific BART, an air quality modeling study was conducted to determine whether visibility improvement resulting from implementation of the Transport Rule meets the two-pronged visibility test for demonstrating "greater reasonable progress" than source-specific BART.

Section 2.0 of this document describes the development of the emission projections that are the basis for the air quality and visibility modeling in the Transport Rule Is "Better-than – BART" analysis. Section 2.1 describes the underlying inventory of BART units and the modeling criteria used to constrain each control scenario. National and state-specific emission projections from the Integrated Planning Model (IPM) are described in section 2.2. Section 3.0 of this TSD describes the air quality modeling performed for this analysis including the modeling process and methodology, and calculation of visibility impacts for each control scenario. Projected visibility impacts for each control scenario are shown for each mandatory Class I Federal area (for which there were sufficient data). Appendix A lists the inventory of BART-eligible units used in the "Nationwide BART" control scenario. Appendix B provides a detailed analysis of the effect of very low nitrate concentrations on visibility results at several Class I areas, and Appendix C describes the potential visibility impacts of proposed revisions to the NOx and $SO_2$ budgets for certain states subject to the Transport Rule. .

## 2.0 Emission Projections Used for Transport Rule Is Better-than-BART Analysis

The air quality modeling conducted for this analysis is based on emission projections for two control scenarios. One scenario represents "Nationwide BART" and the other represents "Transport Rule + BART-elsewhere". The "Nationwide BART" scenario examined $SO_2$ and $NO_X$ emissions from all EGUs nationwide after the application of BART controls to all BART-eligible EGUs. In the "Transport Rule + BART-elsewhere" scenario, EGU $SO_2$ and $NO_X$ emissions reductions attributable to the Transport Rule were applied in the 28-state Transport Rule region and BART controls were applied to all BART-eligible EGUS outside the Transport Rule region that are not subject to Transport Rule requirements. The latter scenario reflects the

fact that source-specific BART would remain a regional haze SIP element outside the Transport Rule region. In order to more accurately project the Transport Rule emissions, it is necessary to assume EGU BART controls outside the Transport Rule region to account for potential load and emission shifting among EGUs.

### 2.1 Eligible BART Units and Modeling Criteria

The first step in developing the control scenarios was to identify EGUs in the contiguous 48 states that are eligible for BART controls and for which EPA has developed presumptive emission limits. These criteria limited the analysis to coal-fired EGUs for which construction commenced by August 7, 1977 and that were not in operation prior to August 7, 1962. The impacts of BART were modeled using stringent assumptions regarding the EGUs (or specific units at EGUs) that would be subject to BART. The Regional Haze rule (RHR) BART Guidelines[3] specify that presumptive limits for NOx and $SO_2$ should be applied to EGUs having a total generating capacity of 750 MW. The Guidelines also exempt from controls BART-eligible units with the potential to emit less than 40 tons per year of either NOx or $SO_2$. In this analysis it was assumed that all BART-eligible EGUs were subject to BART requirements to ensure that controls that states might choose to require on sources not subject to presumptive BART were accounted for in this analysis. It was also assumed that presumptive BART limits would be applied to much smaller units. In this analysis it was assumed that the threshold for BART-eligibility was 100 MW for $SO_2$ and 25 MW for $NO_X$ and no source was eliminated based on their annual total emissions. Appendix A lists the EGUs that were assumed to be BART-subject for the purpose of this analysis.

For both the "Nationwide BART" scenario and the "Transport Rule + BART-elsewhere" scenario, the modeled emission rates were the presumptive EGU BART limits for $SO_2$ and $NO_X$ as specified in the BART Guidelines, unless an actual emission rate at a given unit with existing controls is lower. In the latter case, the lower emission rates were modeled. Version 410 of the National Electric Energy Data System (NEEDS), an EPA database of existing and planned-committed EGUs, was used to identify emission rates for each EGU.[4]

For $SO_2$, the RHR BART Guidelines specify presumptive BART limits for an EGU with an existing scrubber as 95 percent scrubber control efficiency or 0.15 lbs/MMBtu. The NEEDS was used to identify which BART-eligible units have existing scrubbers, the scrubber efficiency at these units and the controlled $SO_2$ emission rate. For scrubbed BART-eligible units the modeled $SO_2$ emission rate was based on a comparison of the $SO_2$ emission rate listed for that

[3] Guidelines for BART Determinations under the Regional Haze Rule, 70 FR 39104, July 6, 2005.
[4] See The NEEDS User Guide: http://www.epa.gov/airmarkets/progsregs/epa-ipm/CSAPR/docs/Guide_to_NEEDSv410.pdf which is found at http://www.epa.gov/airmarkets/progsregs/epa-ipm/transport.html.

unit in NEEDS to the presumptive $SO_2$ limits. For an EGU with a scrubber operating at 95 percent or higher efficiency, the emission rate being achieved at that control efficiency was modeled for that unit even if the emission rate was higher than 0.15 lbs/MMBtu. Conversely, if an emission rate of 0.15 lbs/MMBtu or lower is being achieved, that emission rate was modeled for that unit, even if the scrubber is less than 95 percent efficient. For BART-eligible units without existing scrubbers, an emission rate was modeled that reflected 95 percent control based on a new installation of a highly efficient scrubber.

For NOx, the RHR BART Guidelines specify presumptive limits based on coal type and boiler configuration. The BART guidelines also specify that existing $NO_X$ controls must be operated year round. For the source-specific "Nationwide BART" scenario and for the "elsewhere" EGUs in the "Transport Rule + BART-elsewhere" scenario, it was assumed that any BART-subject unit with existing $NO_X$ controls in the future baseline case would retain at least those controls and would be required to operate them year round. If the existing $NO_X$ controls in the future baseline case did not meet the presumptive BART limits, installation of post-combustion controls (i.e., selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR)) that would meet the BART guidelines with year-round operation was assumed. In the "Transport Rule + BART-elsewhere" scenario, there are 5 states that are subject to the Transport Rule requirements during the ozone season only.[5] For these states, $NO_X$ controls were assumed to operate only during ozone season as required by the Transport Rule.

Table 2-1 summarizes the $NO_X$ emission limits that were applied to BART-eligible units of 25 MW or greater. For units firing a coal blend, which the BART Guidelines do not address, a weighted presumptive $NO_X$ limit based on the percentage of each coal type fired was calculated and modeled.

**Table 2-1.** BART Presumptive $NO_X$ Limits by Boiler Configuration and Coal Type (lbs/MMBtu)

| | **Bituminous** | **Subbituminous** | **Lignite** |
|---|---|---|---|
| Dry bottom wall-fired | 0.39 | 0.23 | 0.29 |
| Tangential-fired | 0.28 | 0.15 | 0.17 |
| Cell burners | 0.40 | 0.45 | Not applicable |
| Dry turbo-fired | 0.32 | 0.23 | Not applicable |
| Wet bottom tangential-fired | 0.62 | Not applicable | Not applicable |
| Cyclone | 0.10 | 0.10 | 0.10 |

BART emission limits modeled for certain EGUs were different from presumptive limits if the EGU has a configuration for which presumptive limits have not been established, or if the EGU has a different emission limit prescribed by a proposed or finalized State Implementation Plan, a

[5] States subject to the Transport Rule requirements during the ozone season only are Oklahoma, Arkansas, Louisiana, Mississippi and Florida.

Federal Implementation Plan, a final consent decree, or by state rule. These units and the emission rates modeled for these units are detailed in Table 2-2.

Note that all but a few of the EGUs listed in Table 2-2 are in states that are not covered by the Transport Rule. Hence, the assumptions about their BART emission rates cannot affect the outcome of the second prong of the "better than BART" test because the emission rates for these EGUs are the same in both the "nationwide BART" and Transport Rule + BART-elsewhere" air quality analyses that are compared in the second prong of the visibility test.

**Table 2-2.** Modeled Emission Rates other than Presumptive Limits for Specific EGUs*

| EGU Name | State | ORIS Plant Code/CAMD UnitID | Modeled NOx Emission Rate (lbs/MMBtu) | Modeled $SO_2$ Emission Rate (lbs/MMBtu) | Comment |
|---|---|---|---|---|---|
| R.M. Heskett B | ND | 2790/1875 | 0.20 | | FBC unit with no presumptive limits established. Used the "general" NOx limit used for this size boiler in the 2005 RHR BART Guidelines. |
| Marion | IL | 976/9173 | 0.20 | | FBC unit with no presumptive limits established. Used the "general" NOx limit used for this size boiler in the 2005 RHR BART Guidelines. |
| Monticello | TX | 6147/2809 | 0.14 | | Wall-fired, wet bottom firing a 50/50 lignite/subbituminous blend. Emission rate per Memo from Rob LaCount re: New NOx requirements in the State of Texas (SB7) |
| Big Bend | FL | 645/467<br>645/468<br>645/469 | 0.12 | | Consent decree |
| Bridgeport | CT | 568/373 | 0.14 (ozone season)<br>0.15 (non-ozone season) | 0.33 | State alternative BART demonstration. |
| Navajo | Tribal | 4941/2662<br>4941/2663<br>4941/2664 | 0.24 | | NOx limit beginning 2009 per voluntary permit limit. |
| San Juan | NM | 2451/1596<br>2451/1597<br>2451/1598<br>2451/1599 | 0.05 | 0.15 | Approved SIP (NOx)<br>Final FIP ($SO_2$) |
| Muskogee | OK | 2952/2005<br>2952/2006 | | 0.06 | Proposed FIP |
| Sooner | OK | 6095/2773<br>6095/2774 | | 0.06 | Proposed FIP |
| Northeastern | OK | 2963/2019<br>2963/2020 | | 0.06 | Proposed FIP |
| Valmont | CO | 477/309 | ------ | ------- | Shutting down in 2017. |
| Howard Down | NJ | 50397/3655 | ------ | ------- | Converted to No. 6 fuel oil in 2010. |
| Edge Moor | DE | 593/383 | 0.15 in 2009<br>0.125 in 2012 | 0.37 in 2009<br>0.26 in 2012 | Delaware state regulation 1146 |
| Indian River | DE | 594/388<br>594/389 | 0.15 in 2009<br>0.125 in 2012 | 0.37 in 2009<br>0.26 in 2012 | Delaware state regulation 1146 |
| Reid Gardner | NV | 2324/1401 | 0.20 | 0.15 | Proposed SIP |

| | | | | | |
|---|---|---|---|---|---|
| | | 2324/1402 | | | |
| Reid Gardner | NV | 2324/1403 | 0.28 | 0.15 | Proposed SIP |
| Four Corners | Tribal | 2442/1581<br>2442/1582<br>2442/1583 | ----- | ----- | Shutdown by 12/31/2014 (proposed FIP). |
| Four Corners | Tribal | 2442/1584<br>2442/1585 | 0.098 | | Unit 1584 installing NOx controls by the end of 2017 and Unit 1585 installing NOx controls by end of 2018 (proposed FIP). |
| KPC&L La Cygne | KS | 1241/819<br>1241/820 | 0.13 weighted average of emissions from both units | 0.10 weighted average of emissions from both units | State consent decree. |
| Jeffrey Energy Center | KS | 6068/2734<br>6068/2735 | 0.15 | 0.15 | State consent decree. |
| Boardman | OR | 6106/2778 | 0.23 beginning July 1, 2011 | 0.4 by 2014 | Interim $SO_2$ limits must be met in 2014. NOx limit must be met beginning July 1, 2011. Facility shutdown in 2020. |

*Where an emission rate is not listed, the presumptive NOx or $SO_2$ emission rate for that EGU configuration was modeled.

## 2.2 Emission Projections

To estimate emissions expected from the control scenarios described in section 2.1, the Integrated Planning Model[6] (IPM) was used. The IPM is a multi-regional, dynamic, deterministic linear programming model of the electric power sector. It is used extensively by the EPA to support regulatory activities. The IPM provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies for meeting electricity demand subject to environmental, transmission, dispatch, and reliability constraints. The IPM was used in this case to evaluate the emissions impacts of the described scenarios limiting the emissions of $SO_2$ and $NO_X$ from EGUs. This analysis used the most recently updated IPM platform which is documented at http://www.epa.gov/crossstaterule/. Table 2-3 presents the annual emissions for each policy scenario as projected by the IPM. As shown by the numbers in the far right column, "Transport Rule + BART-elsewhere" achieved greater emission reductions nationwide[7] for both pollutants than source-specific "Nationwide BART" alone.

**Table 2-3.** National EGU $SO_2$ and $NO_X$ Annual Emissions as Projected by IPM (in thousands of tons per year)

| | 2014 Base Case EGU Emissions | 2014 "Nationwide BART" | 2014 "Transport Rule + BART-elsewhere" | Additional reduction from "Transport Rule + BART-elsewhere" ("Nationwide BART" minus "Transport Rule + BART-elsewhere") |
|---|---|---|---|---|
| National Annual $SO_2$ | 7,160 | 3,820 | 2,918 | 902 |
| National Annual $NO_X$ | 2,089 | 1,798 | 1,756 | 42 |

The IPM projections of annual $NO_X$ and $SO_2$ emissions from EGUs for the "Transport Rule + BART-elsewhere" control scenario summarized in Table 2-3, which were used to arrive at the modeling results presented in section 3.5, are based on the state budgets prescribed in the final Transport Rule published on August 8, 2011 and the supplemental proposal published on July 11, 2011.[8] State-specific emission projections for the 2014 base case and each control scenario are shown for $SO_2$ emissions in Table 2-4 and for NOx emissions in Table 2-5.

[6] Extensive documentation of the IPM platform may be found at http://www.epa.gov/airmarkets/progsregs/epa-ipm/transport.html.

[7] In the context of this analysis, when we refer to nationwide emissions or a nationwide analysis, we are referring to the contiguous 48 states.

[8] Federal Implementation Plans to Reduce Interstate Transport of Fine Particulate Matter and Ozone 76 FR 48208 (August 8, 2011). The ozone season state budgets for the states affected by the supplemental proposal published on July 11, 2001 are included in the "Transport Rule + BART-elsewhere" control scenario (Federal Implementation Plans for Iowa, Kansas, Michigan, Missouri, Oklahoma, and Wisconsin To Reduce Interstate Transport of Ozone, 76 FR 40662).

**Table 2-4.** 2014 Annual $SO_2$ Emissions in the Transport Rule Region and Non-Transport Rule Region States for the 2014 base case and each Control Scenario.

| **Transport Region States** | **2014 Base Case** | **Nationwide BART** | **Transport Rule + BART-elsewhere** | **Non-Transport Region States** | **2014 Base Case** | **Nationwide BART** | **Transport Rule + BART-elsewhere** |
|---|---|---|---|---|---|---|---|
| Alabama | 417.3 | 181.5 | 168.5 | Arkansas | 99.4 | 38.1 | 39.7 |
| Georgia | 170.3 | 151.4 | 93.6 | Arizona | 35.6 | 24.6 | 24.6 |
| Illinois | 141.6 | 116.1 | 133.7 | California | 7.3 | 7.4 | 7.3 |
| Indiana | 727.8 | 454.5 | 202.9 | Colorado | 62.1 | 22.4 | 26.6 |
| Iowa | 133.1 | 43.9 | 83.8 | Connecticut | 3.8 | 1.9 | 1.9 |
| Kansas | 69.8 | 19.8 | 49.1 | Delaware | 2.2 | 2.1 | 2.1 |
| Kentucky | 488.0 | 164.9 | 125.4 | Florida | 143.6 | 77.5 | 79.8 |
| Maryland | 42.9 | 36.5 | 28.6 | Idaho | 0.2 | 0.2 | 0.2 |
| Michigan | 269.4 | 141.4 | 174.3 | Louisiana | 118.2 | 81.2 | 92.6 |
| Minnesota | 70.9 | 56.5 | 50.1 | Maine | 2.4 | 2.6 | 2.4 |
| Missouri | 390.3 | 107.9 | 181.8 | Massachusetts | 13.4 | 8.4 | 8.4 |
| Nebraska[9] | 73.1 | 32.9 | 71.2 | Mississippi | 31.0 | 16.3 | 17.8 |
| New Jersey | 38.9 | 26.1 | 6.1 | Montana | 15.4 | 5.9 | 6.7 |
| New York | 42.9 | 42.1 | 18.8 | Nevada | 14.4 | 14.8 | 14.8 |
| North Carolina | 126.0 | 130.9 | 74.0 | New Hampshire | 6.5 | 4.7 | 5.2 |
| Ohio | 851.2 | 546.7 | 190.0 | New Mexico | 11.9 | 10.8 | 11.7 |
| Pennsylvania | 509.6 | 222.6 | 134.5 | North Dakota | 103.6 | 37.7 | 37.0 |
| South Carolina | 213.3 | 114.0 | 101.5 | Oklahoma | 138.0 | 41.4 | 41.4 |
| Tennessee | 284.5 | 321.3 | 66.7 | Oregon | 11.3 | 0.2 | 0.2 |
| Texas | 453.3 | 139.3 | 266.6 | Rhode Island | 0 | 0.0 | 0.0 |
| Virginia | 77.3 | 78.7 | 53.9 | South Dakota | 29.7 | 2.4 | 2.5 |
| West Virginia | 498.5 | 165.1 | 90.4 | Utah | 33.5 | 32.7 | 32.1 |
| Wisconsin | 130.5 | 52.1 | 51.4 | Vermont | 0.3 | 0.3 | 0.3 |
| | | | | Washington | 3.4 | 3.4 | 3.4 |
| **Total** | **6,220.50** | **3,346.20** | **2,416.90** | Wyoming | 51.8 | 37.2 | 42.9 |
| | | | | | | | |
| | | | | Total | **939.00** | **474.20** | **501.60** |

[9] Gerald Gentleman Unit 2 was inadvertently omitted from the inventory of BART-eligible units. $SO_2$ emissions for Nebraska would be approximately 12,000 tons less under the Nationwide BART scenario if Gerald Gentleman Unit 2 had been properly included in the Nationwide BART control scenario; however we do not expect that this difference in emissions would change the outcome of our analysis.

**Table 2- 5.** 2014 Annual NOx Emissions in the Transport Rule Region and Non-Transport Rule Region States for the 2014 base case and each Control Scenario[10]

| Transport Region States | 2014 Base Case | Nationwide BART | Transport Rule + BART-elsewhere | Non-Transport Region States | 2014 Base Case | Nationwide BART | Transport Rule + BART-elsewhere |
|---|---|---|---|---|---|---|---|
| Alabama | 76.0 | 74.1 | 70.3 | Arkansas | 36.3 | 26.2 | 36.9 |
| Georgia | 49.4 | 45.4 | 41.8 | Arizona | 35.6 | 26.0 | 26.0 |
| Illinois | 55.3 | 49.3 | 49.6 | California | 26.9 | 27.0 | 27.1 |
| Indiana | 117.8 | 107.8 | 111.5 | Colorado | 49.4 | 46.9 | 48.0 |
| Iowa | 48.4 | 41.8 | 42.4 | Connecticut | 2.9 | 2.7 | 2.5 |
| Kansas | 32.6 | 22.6 | 24.4 | Delaware | 1.7 | 1.8 | 1.7 |
| Kentucky | 83.5 | 75.4 | 78.0 | Florida | 100.6 | 81.0 | 75.7 |
| Maryland | 17.6 | 15.6 | 16.8 | Idaho | 0.6 | 0.6 | 0.6 |
| Michigan | 67.7 | 64.7 | 62.3 | Louisiana | 31.6 | 31.7 | 31.7 |
| Minnesota | 41.5 | 34.1 | 35.1 | Maine | 5.4 | 6.2 | 5.4 |
| Missouri | 57.3 | 50.3 | 51.2 | Massachusetts | 7.0 | 7.2 | 7.1 |
| Nebraska | 45.0 | 30.2 | 28.1 | Mississippi | 26.3 | 19.7 | 19.5 |
| New Jersey | 8.0 | 8.1 | 7.8 | Montana | 19.4 | 13.4 | 13.5 |
| New York | 21.7 | 21.8 | 20.5 | Nevada | 14.1 | 13.8 | 13.9 |
| North Carolina | 49.3 | 52.2 | 45.4 | New Hampshire | 5.1 | 3.1 | 3.0 |
| Ohio | 104.1 | 96.9 | 90.1 | New Mexico | 64.7 | 13.0 | 13.0 |
| Pennsylvania | 134.1 | 122.3 | 118.4 | North Dakota | 53.3 | 43.9 | 43.9 |
| South Carolina | 39.0 | 34.3 | 37.0 | Oklahoma | 67.0 | 44.6 | 44.3 |
| Tennessee | 29.3 | 34.7 | 20.5 | Oregon | 9.6 | 2.3 | 2.3 |
| Texas | 142.1 | 139.4 | 139.5 | Rhode Island | 0.4 | 0.4 | 0.5 |
| Virginia | 40.5 | 41.9 | 39.1 | South Dakota | 14.3 | 2.5 | 2.6 |
| West Virginia | 64.8 | 65.7 | 53.2 | Utah | 67.4 | 61.7 | 62.2 |
| Wisconsin | 40.7 | 36.5 | 34.5 | Vermont | 0.5 | 0.5 | 0.5 |
| | | | | Washington | 13.3 | 10.0 | 10.0 |
| **Total** | **1,365.70** | **1,265.10** | **1,217.50** | Wyoming | 70.2 | 46.5 | 46.5 |
| | | | | | | | |
| | | | | **Total** | **723.60** | **532.70** | **538.40** |

[10] Due to limitations in the IPM model, NOx emissions from a small number of units were underestimated in the "National BART" run. At the national level, the NOx emissions that were underestimated account for about 0.22% of national emissions which is not significant for the scope of this analysis.

## 3.0 Air Quality Modeling to Determine Future Visibility

In this section we describe the photochemical air quality modeling performed to support the finding that compliance with the Transport rule for EGUs will result in greater visibility improvement in Federal Class I areas than source-specific BART.

This section also includes technical information on the air quality model applied in support of the proposed rule, and the procedures for projecting regional haze for future year scenarios. The Transport Rule Air Quality Modeling - Final Rule Technical Support Document (TR-AQMTSD)[11] contains more detailed information on the air quality modeling aspects of this rule. This technical support document provides additional information, including further details on the post-processing of model results and calculation for visibility and visibility metrics.

### 3.1 Overview of the Modeling Process

We completed numerous modeling runs and post-processing calculations to determine the impacts of emissions and emissions control strategies on visibility in Class I areas. Determining such visibility impacts allows for the comparison of the effects of compliance with a "Nationwide BART" program (for EGUs) to the final Transport Rule, as represented by the "Transport rule + BART-elsewhere" scenario. We detail these calculations and the modeling process in subsequent sections, following a brief description of the overall process.

The cornerstone of our modeling process was the 2014 base case modeling scenario, which contains emissions for 2014 based on predicted growth and existing emissions controls.[12] We used model-predicted changes in visibility impairment along with the observed base year visibility values to estimate future visibility impairment at each Class I area. We applied the relative predicted change in visibility (expressed as a percent) from the model, due to emissions changes, to the base year visibility values to estimate future visibility. The projected visibility values were based on emissions changes between the 2005 base year inventory and the 2014 inventory.

After we established the future year 2014 base case visibility values, we calculated estimated visibility improvements at each Class I area by modeling the "Transport Rule + BART-elsewhere" [13] control strategy as well as the "nationwide BART" strategy in 2014.

---

[11] U.S. EPA, Air Quality Modeling - Final Rule Technical Support Document (for the Cross State Air Pollution Rule). June 2011. Docket number EPA-HQ-OAR-2009- 0491 available at http://www.epa.gov/airtransport/pdfs/AQModeling.pdf

[12] This is the same 2014 base case model run used for the Transport Rule. It is a "no CAIR" scenario which assumes that CAIR is not in place in 2014. The basis for this assumption is explained in further detail in the Transport Rule final rule preamble.

[13] The Transport Rule + BART elsewhere strategy is the Transport Rule applied in the region where it is in effect

## 3.2 Overview of the Future Year Visibility Projections

In general, we estimated base and future year visibility impairment using the same modeling approach that was used in the July 2011 Transport Rule final rule modeling to develop base and future year predictions of $PM_{2.5}$ concentrations and visibility impairment. In the final Transport Rule modeling we used the CAMx model (version 5.30) to predict $PM_{2.5}$ levels. We used the CAMx predicted $PM_{2.5}$ components to estimate future year changes in visibility at Class I areas. Details of the application of CAMx for the final Transport Rule, including model performance, can be found in Section V of the Transport Rule NFR preamble and the TR-AQMTSD. Familiarity with that detailed description is assumed for present purposes.

As described in the final TR-AQMTSD, we performed a 2005 Base Year model simulation to examine the ability of the modeling system to replicate observed concentrations of PM and its precursors. We also modeled a future-year base case scenario for 2014. The future-year base case scenario included emissions resulting from growth and emissions controls required under Federal and State law.[14] We completed two additional model runs for this analysis; the "nationwide BART" run and the "Transport Rule + BART-elsewhere" run. We quantified the impacts of the Transport Rule and BART controls on visibility impairment by comparing the results of the future-year 2014 base case model runs with the results of the "Transport Rule + BART-elsewhere" and the "nationwide BART" control strategy model runs. Table 3-1 lists the four CAMx model runs that were used to post-process the visibility results for this proposed rule.

**Table 3-1.** CAMx model scenarios used for the Better than BART analysis

| **Model Scenario** | **Modeling Completed and Documented in the Final Transport rule** | **Modeling Completed and Documented for the Better than BART rule** |
|---|---|---|
| 2005 base case | X | |
| 2014 base case | X | |
| 2014 Nationwide BART | | X |
| 2014 Transport Rule + BART-elsewhere | | X |

Figure 3-1 shows the CAMx modeling domain used for the Transport Rule Better- than-BART model runs. As shown, there is a Continental U.S. 36km domain (the large black box) with a nested Eastern U.S. 12km domain (outlined in red). Visibility results were calculated

and BART applied in the rest of the contiguous U.S., as previously defined.

[14] For the Transport Rule base case modeling, we assumed that CAIR was not in place and only included EGU controls that were otherwise required by Federal or State law or regulations.

using the 12km modeling results for all Class I areas inside of the 12km domain. The 36km modeling results were used for all other Class I areas in the West, outside of the 12km domain.

**Figure 3-1.** CAMx 12km and 36km resolution modeling domains

We quantified visibility impacts at the Class I areas which have complete IMPROVE ambient data for 2005 or are represented by IMPROVE monitors with complete data. Since the base year meteorology used in the CAMx modeling is from 2005, ambient data from 2005 is needed to be able to identify the best and worst observed visibility days. It is necessary to know which days make up the 20 percent best and worst days so that the model outputs can be calculated on the same days. For a Class I area without ambient data in 2005, there is no way to match up the model predicted changes in visibility with the ambient data from the 20 percent best and worst days. There are currently 110 IMPROVE monitoring sites (representing 155 Class I areas[15]) collecting ambient $PM_{2.5}$ data at Class I areas. Of these 110 sites, 104 are in the Continental U.S. Of the 104 sites in the Continental U.S., 96 have complete data for 2005. These 96 sites represent 140 Class I areas.[16]

The 140 Class I area sites are scattered throughout the country and represent all of the IMPROVE defined regional visibility areas.[17] Of the 140 Class I areas, 60 are in the Eastern 12km modeling domain and 80 are in the West, outside of the 12km domain, but inside the 36km

[15] There are 156 Class I areas, but one area (Bering Sea) is not represented by an IMPROVE monitor.
[16] The matching of sites to monitors is taken from the Guidance for Tracking Progress Under the Regional Haze Rule, EPA-454/B-03-004, September 2003.
[17] IMPROVE: Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States: Report III (May 2000).

modeling domain.

### 3.3 Calculation of Base Year (Current) Visibility Levels

Base year (current) visibility values at Class I areas were needed to determine the starting point for calculating future year visibility improvements. For the purpose of evaluating visibility for the "better than BART" analysis, visibility impairment was calculated for the 20% worst days and the 20% best days at each Class I area. The calculation of baseline visibility values for each Class I area followed the procedures detailed in the Guidance for Tracking Progress.[18] The baseline visibility on the 20% worst days at each Class I area was calculated using the "new" IMPROVE visibility equation (IMPROVE, 2006). The IMPROVE data was pre-processed[19] for Regional Haze calculations and reformatted to MATS format (EPA, 2010). The daily deciview values were calculated and ranked for each Class I area for each of five years for period 2003-2007.[20] The 20% highest deciview values were identified as the 20% worst days for the year. A similar procedure was followed to get the 20% best days in each Class I area. Table 3-2 shows the base year (2003-2007) estimated visibility impairment (in deciviews) at the 140 Class I areas on the 20% worst days and 20% best days at each area.

**Table 3-2**. Base Year Visibility (2003-2007) on the 20% Best Days and 20% Worst Days, at 140 IMPROVE Sites

| **Class I Area** | **IMPROVE Representative Site** | **IMPROVE Site Identifier** | **State** | **2003-2007 Baseline Visibility (in dv) 20% Best Days** | **2003-2007 Baseline Visibility (in dv) 20% Worst Days** |
|---|---|---|---|---|---|
| Acadia NP | ACAD1 | ACAD | ME | 8.3 | 22.8 |
| Agua Tibia Wilderness | AGTI1 | AGTI | CA | 8.4 | 22.4 |
| Alpine Lake Wilderness | SNPA1 | ALLA | WA | 5.1 | 17.0 |
| Anaconda-Pintler Wilderness | SULA1 | ANAC | MT | 2.4 | 17.1 |
| Ansel Adams Wilderness (Minarets) | KAIS1 | ANAD | CA | 1.9 | 15.2 |
| Arches NP | CANY1 | ARCH | UT | 3.0 | 10.8 |
| Badlands NP | BADL1 | BADL | SD | 6.7 | 16.8 |
| Mount Baldy Wilderness | BALD1 | BALD | AZ | 2.9 | 11.3 |

[18] U.S. EPA, Guidance for Tracking Progress under the Regional Haze Rule (Tracking Progress Guidance) (September 2003).
[19] The IMPROVE data are available at: http://views.cira.colostate.edu/web/DataWizard/
[20] The base case modeling year for this analysis (and for the Transport Rule) was 2005. Therefore, for this analysis, we used visibility data from the five year period centered about the 2005 base year (2003-2007).

| Class I Area | IMPROVE Representative Site | IMPROVE Site Identifier | State | 2003-2007 Baseline Visibility (in dv) 20% Best Days | 2003-2007 Baseline Visibility (in dv) 20% Worst Days |
|---|---|---|---|---|---|
| Bandelier NM | BAND1 | BAND | NM | 4.6 | 12.0 |
| Big Bend NP | BIBE1 | BIBE | TX | 5.7 | 17.2 |
| Black Canyon of the Gunnison NM | WEMI1 | BLCA | CO | 2.8 | 10.0 |
| Bosque del Apache | BOAP1 | BOAP | NM | 6.1 | 13.8 |
| Bob Marshall Wilderness | MONT1 | BOMA | MT | 3.3 | 16.1 |
| Boundary Waters Canoe Area | BOWA1 | BOWA | MN | 5.9 | 20.2 |
| Bryce Canyon NP | BRCA1 | BRCA | UT | 2.4 | 11.6 |
| Bridger Wilderness | BRID1 | BRID | WY | 1.7 | 10.7 |
| Brigantine | BRIG1 | BRIG | NJ | 14.3 | 28.7 |
| Cabinet Mountains Wilderness | CABI1 | CABI | MT | 3.3 | 14.3 |
| Caney Creek Wilderness | CACR1 | CACR | AR | 11.8 | 26.7 |
| Canyonlands NP | CANY1 | CANY | UT | 3.0 | 10.8 |
| Capitol Reef NP | CAPI1 | CAPI | UT | 3.2 | 10.9 |
| Caribou Wilderness | LAVO1 | CARI | CA | 2.5 | 13.7 |
| Carlsbad Caverns NP | GUMO1 | CAVE | TX | 5.6 | 16.5 |
| Chiricahua NM | CHIR1 | CHIR | AZ | 4.6 | 12.9 |
| Chiricahua Wilderness | CHIR1 | CHIW | AZ | 4.6 | 12.9 |
| Cohutta Wilderness | COHU1 | COHU | GA | 13.8 | 30.5 |
| Crater Lake NP | CRLA1 | CRLA | OR | 1.6 | 13.2 |
| Craters of the Moon NM | CRMO1 | CRMO | ID | 3.7 | 14.1 |
| Cucamonga Wilderness | SAGA1 | CUCA | CA | 4.5 | 18.4 |
| Desolation Wilderness | BLIS1 | DESO | CA | 2.3 | 12.9 |
| Diamond Peak Wilderness | CRLA1 | DIPE | OR | 1.6 | 13.2 |
| Dolly Sods Wilderness | DOSO1 | DOSO | WV | 11.2 | 29.9 |
| Eagle Cap Wilderness | STAR1 | EACA | OR | 3.6 | 17.3 |
| Eagles Nest Wilderness | WHRI1 | EANE | CO | 0.9 | 8.8 |
| Emigrant Wilderness | YOSE1 | EMIG | CA | 3.4 | 16.9 |
| Everglades NP | EVER1 | EVER | FL | 12.3 | 22.5 |
| Fitzpatrick Wilderness | BRID1 | FITZ | WY | 1.7 | 10.7 |
| Flat Tops Wilderness | WHRI1 | FLTO | CO | 0.9 | 8.8 |
| Galiuro Wilderness | CHIR1 | GALI | AZ | 4.6 | 12.9 |
| Gates of the Mountains Wilderness | GAMO1 | GAMO | MT | 1.4 | 11.9 |
| Gearhart Mountain Wilderness | CRLA1 | GEMO | OR | 1.6 | 13.2 |
| Gila Wilderness | GICL1 | GICL | NM | 3.1 | 13.1 |

| Class I Area | IMPROVE Representative Site | IMPROVE Site Identifier | State | 2003-2007 Baseline Visibility (in dv) 20% Best Days | 2003-2007 Baseline Visibility (in dv) 20% Worst Days |
|---|---|---|---|---|---|
| Glacier NP | GLAC1 | GLAC | MT | 7.1 | 19.6 |
| Glacier Peak Wilderness | NOCA1 | GLPE | WA | 3.0 | 13.3 |
| Goat Rocks Wilderness | WHPA1 | GORO | WA | 1.6 | 12.7 |
| Grand Canyon NP | GRCA2 | GRCA | AZ | 2.2 | 11.9 |
| Great Gulf Wilderness | GRGU1 | GRGU | NH | 7.0 | 21.4 |
| Great Sand Dunes NM | GRSA1 | GRSA | CO | 3.9 | 11.8 |
| Great Smoky Mountains NP | GRSM1 | GRSM | TN | 13.2 | 30.6 |
| Grand Teton NP | YELL2 | GRTE | WY | 2.2 | 11.2 |
| Guadalupe Mountains NP | GUMO1 | GUMO | TX | 5.6 | 16.5 |
| Hells Canyon Wilderness | HECA1 | HECA | OR | 5.0 | 19.0 |
| Hercules-Glades Wilderness | HEGL1 | HEGL | MO | 13.0 | 27.0 |
| Hoover Wilderness | HOOV1 | HOOV | CA | 1.5 | 11.6 |
| Isle Royale NP | ISLE1 | ISLE | MI | 6.6 | 21.3 |
| Jarbidge Wilderness | JARB1 | JARB | NV | 2.4 | 12.3 |
| James River Face Wilderness | JARI1 | JARI | VA | 14.0 | 28.9 |
| John Muir Wilderness | KAIS1 | JOMU | CA | 1.9 | 15.2 |
| Joshua Tree NM | JOSH1 | JOSH | CA | 5.7 | 18.9 |
| Joyce-Kilmer-Slickrock Wilderness | GRSM1 | JOYC | TN | 13.2 | 30.6 |
| Kaiser Wilderness | KAIS1 | KAIS | CA | 1.9 | 15.2 |
| Kalmiopsis Wilderness | KALM1 | KALM | OR | 6.4 | 16.4 |
| Kings Canyon NP | SEQU1 | KICA | CA | 8.2 | 23.7 |
| Lava Beds NM | LABE1 | LABE | CA | 3.0 | 14.1 |
| La Garita Wilderness | WEMI1 | LAGA | CO | 2.8 | 10.0 |
| Lassen Volcanic NP | LAVO1 | LAVO | CA | 2.5 | 13.7 |
| Linville Gorge Wilderness | LIGO1 | LIGO | NC | 11.3 | 29.7 |
| Lostwood | LOST1 | LOST | ND | 8.0 | 19.6 |
| Lye Brook Wilderness | LYBR1 | LYBR | VT | 5.8 | 24.1 |
| Maroon Bells-Snowmass Wilderness | WHRI1 | MABE | CO | 0.9 | 8.8 |
| Mammoth Cave NP | MACA1 | MACA | KY | 16.5 | 32.0 |
| Mazatzal Wilderness | IKBA1 | MAZA | AZ | 5.4 | 14.0 |
| Medicine Lake | MELA1 | MELA | MT | 6.6 | 18.2 |
| Mesa Verde NP | MEVE1 | MEVE | CO | 3.7 | 12.1 |
| Mission Mountains Wilderness | MONT1 | MIMO | MT | 3.3 | 16.1 |
| Mount Hood Wilderness | MOHO1 | MOHO | OR | 1.8 | 14.7 |

| Class I Area | IMPROVE Representative Site | IMPROVE Site Identifier | State | 2003-2007 Baseline Visibility (in dv) 20% Best Days | 2003-2007 Baseline Visibility (in dv) 20% Worst Days |
|---|---|---|---|---|---|
| Mount Jefferson Wilderness | THSI1 | MOJE | OR | 2.7 | 15.8 |
| Mokelumne Wilderness | BLIS1 | MOKE | CA | 2.3 | 12.9 |
| Mountain Lakes Wilderness | CRLA1 | MOLA | OR | 1.6 | 13.2 |
| Moosehorn | MOOS1 | MOOS | ME | 8.6 | 21.2 |
| Mount Rainier NP | MORA1 | MORA | WA | 5.1 | 17.1 |
| Mount Washington Wilderness | THSI1 | MOWA | OR | 2.7 | 15.8 |
| Mount Zirkel Wilderness | MOZI1 | MOZI | CO | 1.2 | 9.7 |
| North Absaroka Wilderness | NOAB1 | NOAB | WY | 1.7 | 11.3 |
| North Cascades NP | NOCA1 | NOCA | WA | 3.0 | 13.3 |
| Okefenokee | OKEF1 | OKEF | GA | 14.9 | 27.2 |
| Olympic NP | OLYM1 | OLYM | WA | 5.7 | 15.8 |
| Otter Creek Wilderness | DOSO1 | OTCR | WV | 11.2 | 29.9 |
| Pasayten Wilderness | PASA1 | PASA | WA | 2.6 | 15.4 |
| Pecos Wilderness | WHPE1 | PECO | NM | 1.4 | 9.6 |
| Petrified Forest NP | PEFO1 | PEFO | AZ | 5.0 | 13.6 |
| Pine Mountain Wilderness | IKBA1 | PIMO | AZ | 5.4 | 14.0 |
| Pinnacles NM | PINN1 | PINN | CA | 8.3 | 17.9 |
| Point Reyes NS | PORE1 | PORE | CA | 9.7 | 22.4 |
| Presidential Range-Dry River Wilderness | GRGU1 | PRRA | NH | 7.0 | 21.4 |
| San Rafael Wilderness | RAFA1 | RAFA | CA | 5.9 | 19.4 |
| Rawah Wilderness | MOZI1 | RAWA | CO | 1.2 | 9.7 |
| Red Rock Lakes | YELL2 | REDR | WY | 2.2 | 11.2 |
| Redwood NP | REDW1 | REDW | CA | 5.8 | 18.6 |
| Roosevelt Campobello International Park | MOOS1 | ROCA | ME | 8.6 | 21.2 |
| Cape Romain | ROMA1 | ROMA | SC | 15.1 | 27.4 |
| Rocky Mountain NP | ROMO1 | ROMO | CO | 2.3 | 12.9 |
| Salt Creek | SACR1 | SACR | NM | 7.9 | 18.3 |
| San Gabriel Wilderness | SAGA1 | SAGA | CA | 4.5 | 18.4 |
| San Gorgonio Wilderness | SAGO1 | SAGO | CA | 5.0 | 21.4 |
| Saguaro NM | SAGU1 | SAGU | AZ | 7.0 | 14.4 |
| San Jacinto Wilderness | SAGO1 | SAJA | CA | 5.0 | 21.4 |
| San Pedro Parks Wilderness | SAPE1 | SAPE | NM | 1.5 | 10.4 |
| Sawtooth Wilderness | SAWT1 | SAWT | ID | 3.7 | 15.0 |
| Scapegoat Wilderness | MONT1 | SCAP | MT | 3.3 | 16.1 |

| Class I Area | IMPROVE Representative Site | IMPROVE Site Identifier | State | 2003-2007 Baseline Visibility (in dv) 20% Best Days | 2003-2007 Baseline Visibility (in dv) 20% Worst Days |
|---|---|---|---|---|---|
| Selway-Bitterroot Wilderness | SULA1 | SELW | MT | 2.4 | 17.1 |
| Seney | SENE1 | SENE | MI | 7.1 | 25.1 |
| Sequoia NP | SEQU1 | SEQU | CA | 8.2 | 23.7 |
| Shenandoah NP | SHEN1 | SHEN | VA | 10.2 | 29.4 |
| Shining Rock Wilderness | SHRO1 | SHRO | NC | 7.3 | 28.5 |
| Sierra Ancha Wilderness | SIAN1 | SIAN | AZ | 5.7 | 14.5 |
| Sipsey Wilderness | SIPS1 | SIPS | AL | 15.3 | 29.9 |
| South Warner Wilderness | LABE1 | SOWA | CA | 3.0 | 14.1 |
| Strawberry Mountain Wilderness | STAR1 | STMO | OR | 3.6 | 17.3 |
| Superstition Wilderness | TONT1 | SUPE | AZ | 6.0 | 14.2 |
| Sycamore Canyon Wilderness | SYCA1 | SYCA | AZ | 5.3 | 15.5 |
| Teton Wilderness | YELL2 | TETO | WY | 2.2 | 11.2 |
| Three Sisters Wilderness | THSI1 | THIS | OR | 2.7 | 15.8 |
| Thousand Lakes Wilderness | LAVO1 | THLA | CA | 2.5 | 13.7 |
| Theodore Roosevelt NP | THRO1 | THRO | ND | 7.1 | 17.9 |
| UL Bend | ULBE1 | ULBE | MT | 4.4 | 15.5 |
| Upper Buffalo Wilderness | UPBU1 | UPBU | AR | 12.0 | 27.0 |
| Ventana Wilderness | PINN1 | VENT | CA | 8.3 | 17.9 |
| Voyageurs NP | VOYA2 | VOYA | MN | 6.8 | 19.6 |
| Washakie Wilderness | NOAB1 | WASH | WY | 1.7 | 11.3 |
| West Elk Wilderness | WHRI1 | WEEL | CO | 0.9 | 8.8 |
| Weminuche Wilderness | WEMI1 | WEMI | CO | 2.8 | 10.0 |
| White Mountain Wilderness | WHIT1 | WHIT | NM | 3.4 | 13.0 |
| Mount Adams Wilderness | WHPA1 | WHPA | WA | 1.6 | 12.7 |
| Wheeler Peak Wilderness | WHPE1 | WHPE | NM | 1.4 | 9.6 |
| Wind Cave NP | WICA1 | WICA | SD | 4.9 | 16.0 |
| Wichita Mountains | WIMO1 | WIMO | OK | 9.9 | 23.6 |
| Wolf Island | OKEF1 | WOLF | GA | 14.9 | 27.2 |
| Yellowstone NP | YELL2 | YELL | WY | 2.2 | 11.2 |
| Yosemite NP | YOSE1 | YOSE | CA | 3.4 | 16.9 |

### 3.4 Projection of Future Year Visibility Level

The visibility impacts of the Transport Rule and nationwide BART $SO_2$ and $NO_X$ emissions reductions were examined in terms of the projected improvements in visibility on the 20 percent best and worst visibility days at the Class I areas. We quantified visibility impacts for the 140 Class I areas (listed in Table 3-2) in the Continental U.S. modeling domain which have complete IMPROVE ambient data for 2005 or are represented by IMPROVE monitors with complete data.

Visibility values for the 2014 base case and 2014 Transport Rule and nationwide BART scenarios were calculated using the regional haze methodology outlined in section 6 of the photochemical modeling guidance.[21] This photochemical modeling guidance recommends the calculation of future year changes in visibility in a similar manner to the calculation of changes in $PM_{2.5}$ design values. The regional haze methodology for calculating future year visibility impairment is codified in EPA's MATS software, which was used to post-process the modeling runs for this analysis. This software can be found at: (http://www.epa.gov/scram001/modelingapps_mats.htm).

In calculating visibility impairment, the extinction coefficient values[22] are made up of individual component species (sulfate, nitrate, organics, etc). The predicted change in visibility (on the 20 percent best and worst days) is calculated as the modeled percent change in the mass for each of the $PM_{2.5}$ species and for coarse mass (on the 20% best and worst observed days) multiplied by the observed concentrations. The future mass of each component species is converted to extinction and then daily species extinction coefficients are summed to get a daily total extinction value (including Rayleigh scattering). The daily extinction coefficients are converted to deciviews and averaged across all 20 percent best or worst days. In this way, we calculate an average change in deciviews from the base case to a future case at each IMPROVE site. Subtracting the 2014 "Transport Rule + BART-elsewhere" scenario deciview values from the corresponding 2014 base case deciview values gives an estimate of the visibility benefits in Class I areas that are expected to occur from "Transport Rule + BART-elsewhere" . Likewise, subtracting the 2014 "nationwide BART" scenario deciview values from the corresponding 2014 base case deciview values gives an estimate of the visibility benefits in Class I areas that are expected to occur from "nationwide BART".

The following options were chosen in MATS for calculating the future year visibility values for the rule:

---

[21] Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze, U.S. EPA, EPA-454/B-07-002, April 2007, which is found at: http://www.epa.gov/scram001/guidance/guide/final-03-pm-rh-guidance.pdf.

[22] Extinction coefficient is in units of inverse megameters ($Mm^{-1}$).It is a measure of how much light is absorbed or scattered as it passes through a medium. Light extinction is commonly used as a measure of visibility impairment in the regional haze program.

New IMPROVE algorithm
Use model grid cells at (IMPROVE) monitor
Temporal adjustment at monitor- 3x3 for 12km grid, (1x1 for 36km grid)
Start monitor year- 2003
End monitor year- 2007
Base model year 2005
Minimum years required for a valid monitor- 3

The "base model year" was chosen as 2005 because it is the base case meteorological year for the final Transport Rule modeling. The start and end years were chosen as 2003 and 2007 because that is the 5 year period which is centered on the base model year of 2005. These choices are consistent with using a 5 year base period for regional haze calculations.

### 3.5 Details of the Visibility Projection Methodology

The modeling guidance recommends that model predictions be used in a relative sense to estimate changes expected to occur in each major PM species that are used to estimate visibility impairment on the 20% best and worst days. These species are ammonium sulfate, ammonium nitrate, organic carbon mass, elemental carbon, crustal mass, sea salt, and coarse mass. Day-specific observations for mass associated with $SO_4$, $NO_3$, OC, EC, soil, and CM, are used to calculate $b_{ext}$ for each day. The appropriate month- and area-specific climatological relative humidity adjustment factor(s) (*f(rh)*) are used to calculate extinction values. Total $b_{ext}$ for all components are converted to deciviews for each day to get a daily deciview value.

The steps in the visibility impairment calculation are detailed below:

**Step 1.** Calculate the average baseline deciviews for the 20% of days with worst and the 20% days with best visibility.

For each of the 5 years in the base period, order all days from worst (highest deciview value) to best (lowest deciview value) visibility. For each year, note the 20% of days with worst and the 20% of days with best visibility. Calculate the arithmetic mean deciview value for the identified 20% worst- and best visibility days in each year. Average the resulting 5 yearly mean deciview values reflecting worst visibility. Average the 5 yearly mean deciview values reflecting mean visibility on the days with best visibility.

**Step 2**. Estimate relative response factors (RRF) for each component of $PM_{2.5}$ and for coarse mass (CM).

This is done using the modeled species concentrations on the measured best and worst days in 2005 at each IMPROVE site. Take the arithmetic mean concentration for each $PM_{2.5}$

component (and coarse mass) computed at the Class I area monitoring site from the 2014 future emissions case and divide this by the corresponding arithmetic mean concentration for each component obtained with base year (2005) emissions. The resulting quotients are the component-specific RRF's. A separate set of RRF values are calculated for the "worst" and "best" visibility days identified in step 1. The RRFs are calculated using the identified 20% best and 20% worst **monitored days** at each Class I area.

**Step 3.** Using the RRFs and ambient data, calculate future year daily concentration data for the best and worst days.

Multiply the relative response factors derived in Step 2 times measured daily concentration data for each component of $PM_{2.5}$ and CM to get future daily estimates of species concentrations for $PM_{2.5}$ components and CM on "worst visibility" and "best visibility" days. These multiplications produce future concentration estimates for $SO_4$, $NO_3$, OC, EC, Soil and CM for each of the previously selected "worst" and "best" visibility days. This calculation is performed for each best and worst day for the five year period using an RRF for each PM component (a separate set of RRFs for the best days and the worst days)

.

**Step 4.** Use the information developed in Step 3 to compute future year daily $b_{ext}$ values for the best and worst days.

Use the future year concentration data calculated in step 3 to calculate future year daily $b_{ext}$ values for each PM component for each of the best and worst days for the five year period. This is accomplished by applying the "new" IMPROVE visibility algorithm shown below:

$$
\begin{aligned}
\mathbf{b_{ext} \approx\ } & \mathbf{2.2 \times f_s(RH) \times [Small\ Sulfate] + 4.8 \times f_L(RH) \times [Large\ Sulfate]} \\
& \mathbf{+ 2.4 \times f_s(RH) \times [Small\ Nitrate] + 5.1 \times f_L(RH) \times [Large\ Nitrate]} \\
& \mathbf{+ 2.8 \times \{Small\ Organic\ Mass] + 6.1 \times [Large\ Organic\ Mass]} \\
& \mathbf{+ 10 \times [Elemental\ Carbon]} \\
& \mathbf{+ 1 \times [Fine\ Soil]} \\
& \mathbf{+ 1.7 \times f_{ss}(RH) \times [Sea\ Salt]} \\
& \mathbf{+ 0.6 \times [Coarse\ Mass]} \\
& \mathbf{+ Rayleigh\ Scattering\ (site\ specific)}
\end{aligned}
$$

The total sulfate, nitrate and organic carbon compound concentrations are each split into two fractions, representing small and large size distributions of those components. The organic mass concentration used in the new algorithm is 1.8 times the organic carbon mass concentration, changed from 1.4 times carbon mass concentration used for input into the old IMPROVE algorithm. Site-specific Rayleigh scattering is calculated for the elevation and annual average temperature of each IMPROVE monitoring site.

The apportionment of the total concentration of sulfate compounds into the concentrations of the small and large size fractions is accomplished using the following equations.

[Large Sulfate] = [Total Sulfate]/20 ug/m3 x [Total Sulfate], for [Total Sulfate] < 20 ug/m3

[Large Sulfate] = [Total Sulfate], for [Total Sulfate] ≥ 20 ug/m3

[Small Sulfate] = [Total Sulfate] - [Large Sulfate]

The same equations are used to apportion total nitrate and total organic mass concentrations into the small and large size fractions.

Sea salt is calculated as 1.8 x [Chloride] or 1.8 x [Chlorine] if the chloride measurement is below detection limits, missing or invalid. The algorithm also uses three new water growth adjustment terms. They are for use with the small size distribution and the large size distribution sulfate and nitrate compounds and for sea salt ($f_S$(RH), $f_L$(RH) and $f_{SS}$(RH) respectively).[23]

**Step 5.** Use the daily total $b_{ext}$ values from step 4 to calculate future mean deciview values for the best and worst days.

The total daily $b_{ext}$ for each day is converted to deciviews. This gives a future year daily deciview value for each of the best and worst days at each site.

Next, compute the arithmetic mean future deciview value for the "worst" and "best" visibility days for each year. This leads to 5 future estimated mean deciview values for the "worst" and 5 future estimated mean deciview values for the "best" visibility days. Compute the arithmetic mean of the 5 mean values for deciviews on the "worst" days, and the arithmetic mean of the 5 mean deciview values estimated for the "best" visibility days.

### 3.6 Modeling Analysis of the Better than BART Two Pronged Test

The visibility improvements from the Transport Rule + BART-elsewhere strategy were compared to the nationwide BART visibility improvements, in accordance with the two-pronged test for "better-than-BART" determinations set out in the Regional Haze Rule at § 51.308(e)(3).

[23] Default values for site specific Rayleigh scattering and the f(rh) terms were supplied in the IMPROVE data available at on the VIEWS website.

The better-than-BART test is a two pronged test. Under the first prong, visibility must not decline at any Class I area, as determined by comparing the predicted visibility impacts at each affected Class I area under the "Transport Rule + BART-elsewhere" scenario with future baseline (2014) visibility conditions. Under the second prong, overall visibility as measured by the average improvement at all affected Class I areas must be better under the "Transport Rule + BART-elsewhere" scenario than under "Nationwide BART". The future year air quality modeling results were used to make this demonstration.

### 3.6.1 Better than BART Test- 1st Prong

We did two separate analyses to assess the potential visibility impacts of "Transport Rule + BART-elsewhere" and "Nationwide BART" controls. We analyzed one set of results ("first approach") for the 60 Class I areas in the Transport Rule region (the Eastern 12km modeling domain) and a second set of results ("second approach") for the 140 Class I areas in the contiguous 48 states (referred to as the national region). For both visibility scenarios we quantified the visibility impacts on the 20 percent best and 20 percent worst visibility days for the 2014 future-year base case, the "Transport Rule + BART-elsewhere" scenario, and the "Nationwide BART" control scenario. Under the first prong of the test, visibility cannot degrade at any affected Class I area. To determine if "Transport Rule + BART-elsewhere" resulted in degradation of visibility at any affected Class I area we compared the visibility impacts of "Transport Rule + BART-elsewhere" to base case 2014 visibility conditions.

Table 3-3 shows the projected visibility on the 20% best days and 20% worst days at each Class I area in the 2014 baseline and from the "Transport Rule + BART-elsewhere" control strategy. Under the degradation test (1st prong), there should be no degradation from the Transport Rule scenario compared to the 2014 baseline. The "no degradation test" column shows the results of subtracting the 2014 baseline visibility values from the 2014 Transport Rule + BART-elsewhere values. In order to pass this test, all values in the degradation test column should be zero or negative.[24]

[24] All differences that are < 0.05 dv were rounded down to 0.0 and are considered to be no degradation. In Tables 3-3 and 3-4, these sites are identified with an * next to the 0.0 in the no degradation-test column. Calculating visibility changes to the nearest tenth of a deciview (rather than the nearest hundredth) is consistent with the practice for implementing the reasonable progress goals under the Regional Haze rule. (See, e.g., Guidelines for Tracking Reasonable Progress, sample calculations in sections 1.8 and 1.11). Therefore, for purposes of the better-than-BART test, we have assumed that changes in visibility of less than 0.05 dv should not be considered degradation.

**Table 3-3**. Projected visibility and visibility change for the 2014 baseline and the 2014 Transport + BART-elsewhere 20% best and worst days, at 140 Class I areas.

| Class I Area (IMPROVE Site) | State | [A] 2014 Baseline Visibility 20% Best Days (dv) | [B] 2014 Baseline Visibility 20% Worst Days (dv) | [C] 2014 TR + BART-Elsewhere Case Visibility 20% Best Days (dv) | [D] 2014 TR + BART-Elsewhere Case Visibility 20% Worst Days (dv) | No Degradation Test 20% Best Days =[C] – [A]* | No Degradation Test 20% Worst Days =[D] – [B]* |
|---|---|---|---|---|---|---|---|
| **Eastern Class I areas (12km modeling domain)** | | | | | | | |
| Acadia NP | ME | 8.0 | 20.1 | 7.9 | 19.0 | 0.0 | -1.1 |
| Badlands NP | SD | 6.3 | 16.0 | 6.2 | 15.4 | -0.1 | -0.6 |
| Bandelier NM | NM | 4.2 | 11.1 | 4.1 | 10.8 | -0.1 | -0.3 |
| Big Bend NP | TX | 5.4 | 16.3 | 5.2 | 15.2 | -0.2 | -1.1 |
| Black Canyon of the Gunnison NM | CO | 2.3 | 9.5 | 2.3 | 9.4 | -0.1 | -0.1 |
| Bosque del Apache | NM | 5.6 | 13.0 | 5.5 | 12.5 | -0.1 | -0.6 |
| Boundary Waters Canoe Area | MN | 5.8 | 18.8 | 5.7 | 17.6 | -0.1 | -1.2 |
| Brigantine | NJ | 13.2 | 25.4 | 12.9 | 22.8 | -0.4 | -2.5 |
| Caney Creek Wilderness | AR | 11.3 | 24.4 | 10.9 | 21.2 | -0.4 | -3.2 |
| Carlsbad Caverns NP | TX | 5.2 | 15.5 | 5.1 | 14.7 | -0.1 | -0.9 |
| Cohutta Wilderness | GA | 12.9 | 26.6 | 12.1 | 22.8 | -0.8 | -3.8 |
| Dolly Sods Wilderness | WV | 10.3 | 27.1 | 9.2 | 21.4 | -1.1 | -5.7 |
| Eagles Nest Wilderness | CO | 0.4 | 8.3 | 0.4 | 8.2 | 0.0 | -0.1 |
| Everglades NP | FL | 11.5 | 20.4 | 11.1 | 19.3 | -0.3 | -1.0 |
| Flat Tops Wilderness | CO | 0.4 | 8.3 | 0.4 | 8.2 | 0.0 | -0.1 |
| Great Gulf Wilderness | NH | 6.7 | 19.2 | 6.6 | 17.4 | -0.1 | -1.8 |
| Great Sand Dunes NM | CO | 3.5 | 11.3 | 3.5 | 11.1 | -0.1 | -0.2 |
| Great Smoky Mountains NP | TN | 12.2 | 27.0 | 11.4 | 23.3 | -0.8 | -3.7 |
| Guadalupe Mountains NP | TX | 5.2 | 15.5 | 5.1 | 14.7 | -0.1 | -0.9 |
| Hercules-Glades Wilderness | MO | 12.2 | 25.2 | 11.6 | 22.7 | -0.6 | -2.5 |
| Isle Royale NP | MI | 6.4 | 19.9 | 6.3 | 18.9 | -0.1 | -1.0 |
| James River Face Wilderness | VA | 12.9 | 25.8 | 12.1 | 21.6 | -0.9 | -4.2 |
| Joyce-Kilmer-Slickrock | TN | 12.2 | 27.0 | 11.4 | 23.3 | -0.8 | -3.7 |

| Class I Area (IMPROVE Site) | State | [A] 2014 Baseline Visibility 20% Best Days (dv) | [B] 2014 Baseline Visibility 20% Worst Days (dv) | [C] 2014 TR + BART-Elsewhere Case Visibility 20% Best Days (dv) | [D] 2014 TR + BART-Elsewhere Case Visibility 20% Worst Days (dv) | No Degradation Test 20% Best Days =[C] – [A]* | No Degradation Test 20% Worst Days =[D] – [B]* |
|---|---|---|---|---|---|---|---|
| Wilderness | | | | | | | |
| La Garita Wilderness | CO | 2.3 | 9.5 | 2.3 | 9.4 | -0.1 | -0.1 |
| Linville Gorge Wilderness | NC | 10.3 | 26.0 | 9.6 | 21.8 | -0.7 | -4.3 |
| Lostwood | ND | 7.9 | 18.8 | 7.8 | 18.3 | -0.1 | -0.5 |
| Lye Brook Wilderness | VT | 5.5 | 20.7 | 5.4 | 18.2 | -0.1 | -2.6 |
| Maroon Bells-Snowmass Wilderness | CO | 0.4 | 8.3 | 0.4 | 8.2 | 0.0 | -0.1 |
| Mammoth Cave NP | KY | 15.3 | 29.5 | 14.1 | 24.4 | -1.2 | -5.1 |
| Medicine Lake | MT | 6.5 | 17.7 | 6.5 | 17.4 | 0.0 | -0.3 |
| Mesa Verde NP | CO | 3.2 | 11.4 | 3.1 | 11.1 | -0.1 | -0.3 |
| Moosehorn | ME | 8.4 | 19.0 | 8.4 | 18.0 | 0.0* | -1.0 |
| Mount Zirkel Wilderness | CO | 1.0 | 9.2 | 1.0 | 9.2 | 0.0 | -0.1 |
| North Absaroka Wilderness | WY | 1.5 | 11.1 | 1.5 | 11.0 | 0.0 | 0.0 |
| Okefenokee | GA | 13.9 | 24.1 | 13.0 | 21.6 | -0.9 | -2.5 |
| Otter Creek Wilderness | WV | 10.3 | 27.1 | 9.2 | 21.4 | -1.1 | -5.7 |
| Pecos Wilderness | NM | 1.0 | 9.0 | 1.0 | 8.9 | -0.1 | -0.2 |
| Presidential Range-Dry River Wilderness | NH | 6.7 | 19.2 | 6.6 | 17.4 | -0.1 | -1.8 |
| Rawah Wilderness | CO | 1.0 | 9.2 | 1.0 | 9.2 | 0.0 | -0.1 |
| Roosevelt Campobello International Park | ME | 8.4 | 19.0 | 8.4 | 18.0 | 0.0* | -1.0 |
| Cape Romain | SC | 13.6 | 24.0 | 12.9 | 21.2 | -0.7 | -2.9 |
| Rocky Mountain NP | CO | 2.0 | 12.2 | 1.9 | 12.1 | 0.0 | -0.1 |
| Salt Creek | NM | 7.3 | 17.1 | 7.2 | 16.4 | -0.1 | -0.7 |
| San Pedro Parks Wilderness | NM | 1.2 | 9.9 | 1.0 | 9.6 | -0.2 | -0.3 |
| Seney | MI | 6.9 | 23.3 | 6.8 | 21.7 | -0.1 | -1.6 |
| Shenandoah NP | VA | 9.0 | 26.2 | 8.2 | 21.2 | -0.8 | -5.0 |
| Shining Rock Wilderness | NC | 6.3 | 24.8 | 5.7 | 21.1 | -0.7 | -3.8 |
| Sipsey Wilderness | AL | 14.5 | 26.5 | 13.6 | 22.8 | -0.9 | -3.7 |

| Class I Area (IMPROVE Site) | State | [A] 2014 Baseline Visibility 20% Best Days (dv) | [B] 2014 Baseline Visibility 20% Worst Days (dv) | [C] 2014 TR + BART-Elsewhere Case Visibility 20% Best Days (dv) | [D] 2014 TR + BART-Elsewhere Case Visibility 20% Worst Days (dv) | No Degradation Test 20% Best Days =[C] – [A]* | No Degradation Test 20% Worst Days =[D] – [B]* |
|---|---|---|---|---|---|---|---|
| Theodore Roosevelt NP | ND | 6.8 | 17.0 | 6.8 | 16.7 | 0.0 | -0.3 |
| UL Bend | MT | 4.2 | 15.2 | 4.2 | 15.2 | 0.0 | -0.1 |
| Upper Buffalo Wilderness | AR | 11.3 | 24.7 | 10.8 | 22.2 | -0.5 | -2.5 |
| Voyageurs NP | MN | 6.6 | 18.4 | 6.5 | 17.4 | -0.1 | -1.0 |
| Washakie Wilderness | WY | 1.5 | 11.1 | 1.5 | 11.0 | 0.0 | 0.0 |
| West Elk Wilderness | CO | 0.4 | 8.3 | 0.4 | 8.2 | 0.0 | -0.1 |
| Weminuche Wilderness | CO | 2.3 | 9.5 | 2.3 | 9.4 | -0.1 | -0.1 |
| White Mountain Wilderness | NM | 3.1 | 12.3 | 3.0 | 11.7 | -0.1 | -0.6 |
| Wheeler Peak Wilderness | NM | 1.0 | 9.0 | 1.0 | 8.9 | -0.1 | -0.2 |
| Wind Cave NP | SD | 4.6 | 15.1 | 4.6 | 14.8 | 0.0 | -0.3 |
| Wichita Mountains | OK | 9.1 | 21.7 | 8.9 | 20.2 | -0.2 | -1.6 |
| Wolf Island | GA | 13.9 | 24.1 | 13.0 | 21.6 | -0.9 | -2.5 |
| **Western Class I Areas (36km Modeling Domain)** | | | | | | | |
| Agua Tibia Wilderness | CA | 7.9 | 20.2 | 7.8 | 20.2 | 0.0 | 0.0 |
| Alpine Lake Wilderness | WA | 4.6 | 15.8 | 4.6 | 15.7 | 0.0* | 0.0 |
| Anaconda-Pintler Wilderness | MT | 2.3 | 16.8 | 2.3 | 16.8 | 0.0 | 0.0 |
| Ansel Adams Wilderness (Minarets) | CA | 1.7 | 14.6 | 1.7 | 14.6 | 0.0 | 0.0 |
| Arches NP | UT | 2.6 | 9.8 | 2.6 | 9.6 | -0.1 | -0.2 |
| Mount Baldy Wilderness | AZ | 2.5 | 10.9 | 2.4 | 10.9 | -0.1 | 0.0* |
| Bob Marshall Wilderness | MT | 3.1 | 15.8 | 3.1 | 15.8 | 0.0 | -0.1 |
| Bryce Canyon NP | UT | 2.4 | 10.8 | 2.4 | 10.7 | 0.1# | -0.1 |
| Bridger Wilderness | WY | 1.6 | 10.4 | 1.6 | 10.3 | 0.0 | -0.1 |
| Cabinet Mountains Wilderness | MT | 3.0 | 14.0 | 3.0 | 13.9 | 0.0* | -0.1 |
| Canyonlands NP | UT | 2.6 | 9.8 | 2.6 | 9.6 | -0.1 | -0.2 |
| Capitol Reef NP | UT | 2.9 | 10.3 | 2.9 | 10.2 | 0.0 | -0.2 |

| Class I Area (IMPROVE Site) | State | [A] 2014 Baseline Visibility 20% Best Days (dv) | [B] 2014 Baseline Visibility 20% Worst Days (dv) | [C] 2014 TR + BART-Elsewhere Case Visibility 20% Best Days (dv) | [D] 2014 TR + BART-Elsewhere Case Visibility 20% Worst Days (dv) | No Degradation Test 20% Best Days =[C] – [A]* | No Degradation Test 20% Worst Days =[D] – [B]* |
|---|---|---|---|---|---|---|---|
| Caribou Wilderness | CA | 2.3 | 13.2 | 2.3 | 13.2 | 0.0 | 0.0 |
| Chiricahua NM | AZ | 4.4 | 12.4 | 4.4 | 12.4 | -0.1 | -0.1 |
| Chiricahua Wilderness | AZ | 4.4 | 12.4 | 4.4 | 12.4 | -0.1 | -0.1 |
| Crater Lake NP | OR | 1.5 | 12.7 | 1.5 | 12.7 | 0.0 | 0.0 |
| Craters of the Moon NM | ID | 3.5 | 13.7 | 3.5 | 13.6 | 0.0 | 0.0 |
| Cucamonga Wilderness | CA | 3.9 | 16.4 | 3.9 | 16.4 | 0.0 | 0.0 |
| Desolation Wilderness | CA | 2.1 | 12.4 | 2.1 | 12.4 | 0.0 | 0.0 |
| Diamond Peak Wilderness | OR | 1.5 | 12.7 | 1.5 | 12.7 | 0.0 | 0.0 |
| Eagle Cap Wilderness | OR | 3.5 | 16.9 | 3.4 | 16.9 | 0.0 | 0.0* |
| Emigrant Wilderness | CA | 3.1 | 16.2 | 3.1 | 16.2 | 0.0 | 0.0 |
| Fitzpatrick Wilderness | WY | 1.6 | 10.4 | 1.6 | 10.3 | 0.0 | -0.1 |
| Galiuro Wilderness | AZ | 4.4 | 12.4 | 4.4 | 12.4 | -0.1 | -0.1 |
| Gates of the Mountains Wilderness | MT | 1.2 | 11.6 | 1.2 | 11.6 | 0.0 | -0.1 |
| Gearhart Mountain Wilderness | OR | 1.5 | 12.7 | 1.5 | 12.7 | 0.0 | 0.0 |
| Gila Wilderness | NM | 2.9 | 13.0 | 2.9 | 12.9 | 0.0 | -0.2 |
| Glacier NP | MT | 6.8 | 19.1 | 6.8 | 19.0 | 0.0 | 0.0 |
| Glacier Peak Wilderness | WA | 2.9 | 12.6 | 2.9 | 12.6 | 0.0 | 0.0 |
| Goat Rocks Wilderness | WA | 1.5 | 11.9 | 1.5 | 11.9 | 0.0* | -0.1 |
| Grand Canyon NP | AZ | 1.9 | 11.0 | 1.9 | 10.9 | 0.0* | -0.1 |
| Grand Teton NP | WY | 2.0 | 10.9 | 2.0 | 10.9 | 0.0 | 0.0 |
| Hells Canyon Wilderness | OR | 4.8 | 18.3 | 4.7 | 18.3 | 0.0 | 0.0 |
| Hoover Wilderness | CA | 1.3 | 11.2 | 1.3 | 11.2 | 0.0 | 0.0 |
| Jarbidge Wilderness | NV | 2.3 | 12.0 | 2.3 | 12.0 | 0.0 | 0.0 |
| John Muir Wilderness | CA | 1.7 | 14.6 | 1.7 | 14.6 | 0.0 | 0.0 |
| Joshua Tree NM | CA | 5.5 | 17.3 | 5.5 | 17.3 | 0.0 | 0.0 |
| Kaiser Wilderness | CA | 1.7 | 14.6 | 1.7 | 14.6 | 0.0 | 0.0 |

| Class I Area (IMPROVE Site) | State | [A] 2014 Baseline Visibility 20% Best Days (dv) | [B] 2014 Baseline Visibility 20% Worst Days (dv) | [C] 2014 TR + BART-Elsewhere Case Visibility 20% Best Days (dv) | [D] 2014 TR + BART-Elsewhere Case Visibility 20% Worst Days (dv) | No Degradation Test 20% Best Days =[C] – [A]* | No Degradation Test 20% Worst Days =[D] – [B]* |
|---|---|---|---|---|---|---|---|
| Kalmiopsis Wilderness | OR | 6.1 | 16.1 | 6.1 | 16.1 | 0.0 | 0.0 |
| Kings Canyon NP | CA | 7.6 | 21.5 | 7.6 | 21.5 | 0.0 | 0.0 |
| Lava Beds NM | CA | 2.9 | 13.5 | 2.9 | 13.5 | 0.0 | 0.0 |
| Lassen Volcanic NP | CA | 2.3 | 13.2 | 2.3 | 13.2 | 0.0 | 0.0 |
| Mazatzal Wilderness | AZ | 5.0 | 12.9 | 5.0 | 13.2 | 0.0 | 0.2# |
| Mission Mountains Wilderness | MT | 3.1 | 15.8 | 3.1 | 15.8 | 0.0 | -0.1 |
| Mount Hood Wilderness | OR | 1.6 | 13.9 | 1.6 | 13.8 | 0.0 | -0.1 |
| Mount Jefferson Wilderness | OR | 2.6 | 15.4 | 2.6 | 15.3 | 0.0 | 0.0 |
| Mokelumne Wilderness | CA | 2.1 | 12.4 | 2.1 | 12.4 | 0.0 | 0.0 |
| Mountain Lakes Wilderness | OR | 1.5 | 12.7 | 1.5 | 12.7 | 0.0 | 0.0 |
| Mount Rainier NP | WA | 4.8 | 16.0 | 4.7 | 15.9 | 0.0 | -0.1 |
| Mount Washington Wilderness | OR | 2.6 | 15.4 | 2.6 | 15.3 | 0.0 | 0.0 |
| North Cascades NP | WA | 2.9 | 12.6 | 2.9 | 12.6 | 0.0 | 0.0 |
| Olympic NP | WA | 5.4 | 15.1 | 5.4 | 15.0 | 0.0 | 0.0 |
| Pasayten Wilderness | WA | 2.4 | 14.8 | 2.4 | 14.7 | 0.0 | -0.1 |
| Petrified Forest NP | AZ | 4.4 | 13.4 | 4.3 | 13.4 | 0.0 | 0.0 |
| Pine Mountain Wilderness | AZ | 5.0 | 12.9 | 5.0 | 13.2 | 0.0 | 0.2# |
| Pinnacles NM | CA | 7.8 | 16.5 | 7.8 | 16.5 | 0.0 | 0.0 |
| Point Reyes NS | CA | 9.0 | 21.2 | 9.0 | 21.2 | 0.0 | 0.0 |
| San Rafael Wilderness | CA | 5.3 | 18.2 | 5.3 | 18.2 | 0.0 | 0.0 |
| Red Rock Lakes | WY | 2.0 | 10.9 | 2.0 | 10.9 | 0.0 | 0.0 |
| Redwood NP | CA | 5.8 | 18.0 | 5.8 | 18.0 | 0.0 | 0.0 |
| San Gabriel Wilderness | CA | 3.9 | 16.4 | 3.9 | 16.4 | 0.0 | 0.0 |
| San Gorgonio Wilderness | CA | 4.6 | 19.7 | 4.6 | 19.7 | 0.0 | 0.0 |
| Saguaro NM | AZ | 6.5 | 13.4 | 6.3 | 13.7 | -0.2 | 0.3# |
| San Jacinto Wilderness | CA | 4.6 | 19.7 | 4.6 | 19.7 | 0.0 | 0.0 |
| Sawtooth | ID | 3.6 | 14.8 | 3.6 | 14.8 | 0.0 | 0.0 |

| Class I Area (IMPROVE Site) | State | [A] 2014 Baseline Visibility 20% Best Days (dv) | [B] 2014 Baseline Visibility 20% Worst Days (dv) | [C] 2014 TR + BART-Elsewhere Case Visibility 20% Best Days (dv) | [D] 2014 TR + BART-Elsewhere Case Visibility 20% Worst Days (dv) | No Degradation Test 20% Best Days =[C] – [A]* | No Degradation Test 20% Worst Days =[D] – [B]* |
|---|---|---|---|---|---|---|---|
| Wilderness | | | | | | | |
| Scapegoat Wilderness | MT | 3.1 | 15.8 | 3.1 | 15.8 | 0.0 | -0.1 |
| Selway-Bitterroot Wilderness | MT | 2.3 | 16.8 | 2.3 | 16.8 | 0.0 | 0.0 |
| Sequoia NP | CA | 7.6 | 21.5 | 7.6 | 21.5 | 0.0 | 0.0 |
| Sierra Ancha Wilderness | AZ | 5.1 | 14.0 | 5.0 | 14.0 | -0.1 | 0.0 |
| South Warner Wilderness | CA | 2.9 | 13.5 | 2.9 | 13.5 | 0.0 | 0.0 |
| Strawberry Mountain Wilderness | OR | 3.5 | 16.9 | 3.4 | 16.9 | 0.0 | 0.0* |
| Superstition Wilderness | AZ | 5.5 | 13.5 | 5.5 | 13.4 | 0.0 | -0.1 |
| Sycamore Canyon Wilderness | AZ | 4.8 | 15.0 | 4.8 | 14.9 | 0.0 | -0.1 |
| Teton Wilderness | WY | 2.0 | 10.9 | 2.0 | 10.9 | 0.0 | 0.0 |
| Three Sisters Wilderness | OR | 2.6 | 15.4 | 2.6 | 15.3 | 0.0 | 0.0 |
| Thousand Lakes Wilderness | CA | 2.3 | 13.2 | 2.3 | 13.2 | 0.0 | 0.0 |
| Ventana Wilderness | CA | 7.8 | 16.5 | 7.8 | 16.5 | 0.0 | 0.0 |
| Mount Adams Wilderness | WA | 1.5 | 11.9 | 1.5 | 11.9 | 0.0* | -0.1 |
| Yellowstone NP | WY | 2.0 | 10.9 | 2.0 | 10.9 | 0.0 | 0.0 |
| Yosemite NP | CA | 3.1 | 16.2 | 3.1 | 16.2 | 0.0 | 0.0 |

**Notes:** Values in the "No Degradation Test" columns are derived by subtracting values in appropriate columns before those have been rounded to the nearest 0.1 dv, and then rounding the result. Thus apparent discrepancies are due to rounding. Negative numbers indicate visibility improvement.
* The result at these Class I areas was a degradation of less than 0.05 deciviews, which when rounded equals 0.0.
# The default visibility test at these areas resulted in visibility degradation. See discussion below and Appendix B for more information on why we do not believe that visibility degradation will actually occur in these areas.

The modeling results show that the "Transport Rule + BART-elsewhere" alternative passed this first prong in the Transport Rule region by not causing visibility degradation at any of the 60 affected Class I areas in the eastern Transport Rule 12km modeling domain (i.e., when using the first approach to identifying affected areas), on either the 20 percent best or the 20

percent worst days.[25] In the national region (i.e., when using the second approach to identifying affected areas), the "Transport Rule + BART-elsewhere" alternative was also predicted to not cause visibility degradation at any affected Class I area on either the 20 percent best of the 20 percent worst days, with a few exceptions. The exceptions were predicted average degradations of 0.23, 0.23, and 0.26 deciviews, respectively, at Pine Mountain Wilderness, Arizona, Mazatzal Wilderness, Arizona[26], and Saguaro National Park, Arizona, on the 20 percent worst days[27] and a predicted degradation of 0.05 deciviews on the 20 percent best days at Bryce Canyon National Park in Utah.[28] Table 3-4 shows the visibility results (with two significant digits) at these four Class I areas for both the "Transport Rule + BART-elsewhere" and the "Nationwide BART" scenario.

**Table 3-4.** Class I areas with predicted visibility degradation using the default visibility calculations

| Class I Area Name | IMPROVE ID | Representative Site | State | TR+BART-elsewhere 20% Best days | TR+BART-elsewhere 20% Worst days | Nationwide BART 20% Best Days | Nationwide BART 20% Worst Days |
|---|---|---|---|---|---|---|---|
| Bryce Canyon NP | BRCA | BRCA1 | UT | 0.05 | -0.08 | 0.06 | -0.10 |
| Mazatzal Wilderness | MAZA | IKBA1 | AZ | -0.02 | 0.23 | -0.02 | 0.23 |
| Pine Mountain Wilderness | PIMO | IKBA1 | AZ | -0.02 | 0.23 | -0.02 | 0.23 |
| Saguaro NM | SAGU | SAGU1 | AZ | -0.24 | 0.26 | -0.19 | -0.09 |

The fact that unexpected degradations at some western Class I areas were predicted for the "Nationwide BART" scenario as well as the "Transport Rule + BART-elsewhere" scenario led us to investigate the CAMx modeling output in more detail. Based on that investigation, we consider the visibility projections for the western portion of the national modeling domain that indicate potential degradation in four western Class I areas under the "Transport Rule + BART-elsewhere" scenario compared to the "Base Case" scenario to be anomalous results that do not indicate the true effects that the "Transport Rule + BART-elsewhere" scenario (or the

[25] Two Class I areas had degradation of < 0.05 dv on the 20% best days and are denoted in the table with a "*". These values were rounded to zero and are considered to be no degradation.

[26] While not part of the two-pronged test, we also compared the baseline scenario to the "Nationwide BART" scenario. The analysis of the national region under the "Nationwide BART" control scenario also projected a degradation of 0.23 deciviews on the 20 percent worst days at Pine Mountain Wilderness and Mazatzal Wilderness, the same as the "Transport Rule + BART-elsewhere" result.

[27] The results for Pine Mountain and Mazatzal were the same because they are both represented by the same IMPROVE monitoring site (Ike's Backbone, IKBA).

[28] Changes in visibility were rounded to the nearest 0.1 deciviews. Therefore, any changes that were less than 0.05 were rounded down and treated as zero. Any changes that were 0.05 or greater were rounded up and treated as potential degradation.

"Nationwide BART" scenario) will have on visibility in these areas.

All four of the Class I areas are located in the western portion of the 36km modeling domain (outside of the 12km modeling domain). In the CAMx output for the grid cells in the vicinity of these four Class I areas, we observed that modeled concentrations of nitrate were very low on most of the 20 percent worst days (and 20 percent best days at Bryce Canyon) in all of the modeling scenarios, including the 2005 and 2014 base cases as well as the "Transport Rule + BART-elsewhere" and "Nationwide BART" cases. Notably, the 2005 base case modeled concentrations were generally a small fraction of monitored ambient nitrate concentrations at the IMPROVE sites for the four Class I areas. In the cases where degradation was calculated, a very small increase in modeled nitrate was observed on several of the worst or best modeled days. This lead to a relatively large modeled percent increase in nitrate. Since the modeled visibility test is based on relative changes in PM species, the very small increase in nitrate has a relatively large impact on the final results.

Further examination of the days when these nitrate increases occur reveals a seemingly random pattern of very small increases and decreases that appear unrelated to EGU emissions changes. This nitrate modeling issue appears similar to a previously noted nitrate chemistry stability issue when modeled concentrations are very small and relative humidity is very low.[29] Thus, we conclude that these positive and negative differences between very low nitrate concentrations are a modeling artifact attributable to the ISORROPIA nitrate mechanism in CAMx for the conditions that apply in this geographic area on these days, and are not reasonable predictors of the true relative effects on visibility of the emission control scenarios.

To further analyze the cause of the visibility degradation, we performed an analysis to illustrate how sensitive the predictions of degradation are to highly variable results on particular days. For each of these four Class I areas, we removed one day of the 20 percent worst or best days with the largest increase in modeled nitrate concentration at from the calculation of 2014 visibility in the "Transport Rule + BART-elsewhere" control case. When the single day is removed, the predicted visibility degradations no longer occur.

Another possible method to address this modeling issue is to set a minimum concentration threshold for use in calculating RRFs for all PM species. Under this approach if the average concentration across all best or worst days at each site is below the minimum threshold, then the RRF would be set to 1.0. If a minimum threshold of 0.01 ug/m$^3$ is used, the degradation no longer occurs at any Class I area. Based on this information, the EPA is

[29]Tong 2005, Numerical instability in the Community Multiscale Air Quality Model and its impacts on aerosol and ozone simulations, available at: http://www.princeton.edu/~mauzeral/papers/CMAQ_instability%20submission.pdf and Bhave 2004, CMAQ Aerosol Module Development: Recent Enhancements and Future Plans, available at: http://www.cmascenter.org/conference/2004/abstracts/Model%20Development/bhave_abstract.pdf

considering whether to implement a minimum threshold concentration as part of the Regional Haze calculations. The minimum threshold would be built into the MATS software used to post-process photochemical outputs. These possible revisions are aimed at avoiding potentially misleading results in situations such as the one observed near these Western Class I areas.

Based on these detailed analyses, we are confident that no degradation in the four western Class I areas will result from implementation of the Transport Rule trading program in the Eastern U.S.(or from BART). Consequently, we are proposing that the "Transport Rule + BART-elsewhere" control scenario passes the first prong of the visibility test considering affected Class I areas located in both the Transport Rule region (first approach) and the national region (second approach). Additional details on the analysis of this issue, including the sensitivity analyses where we removed individual days and set a minimum concentration threshold for the RRF calculation can be found in Appendix B.

### 3.6.2 Better than BART Test - 2nd Prong

The second prong of the Better than BART test assesses whether the "Transport Rule + BART-elsewhere" scenario results in greater **average** visibility improvement at affected Class I areas compared to the "Nationwide BART" scenario. To determine if "Transport Rule + BART-elsewhere" achieved greater average visibility improvement, we compared the visibility impacts of "Transport Rule + BART-elsewhere" at the Class I areas to visibility impacts predicted at these same areas after implementation of "Nationwide BART".

In the Transport Rule region (first approach) and the national region (second approach), the average visibility improvement should be larger under the "Transport Rule + BART-elsewhere" scenario compared to the "nationwide BART" scenario. Table 3-5 shows the detailed results of the 2nd prong analysis. In order to provide detailed information the modeled visibility change is shown individually for all 140 Class I areas. However, under the greater improvement test, it is acceptable if some Class I areas show greater improvement under the nationwide BART case, as long as the average improvement under the "Transport+ BART-elsewhere" case is larger.

**Table 3-5-** Projected visibility for the 2014 base case and the visibility change in 2014 for the "Transport Rule+ BART-elsewhere" and the "nationwide BART" scenarios on the 20% best and worst days at 140 IMPROVE Sites (including the average change for 60 and 140 areas).

| Class I Areas (IMPROVE Site) | State | 2014 Base Case Visibility 20% Best Days (dv) | 2014 Base Case Visibility 20% Worst Days (dv) | TR – 2014 Base Case 20% Best Days | TR – 2014 Base Case 20% Worst Days | BART – 2014 Base Case 20% Best Days | BART – 2014 Base Case 20% Worst Days |
|---|---|---|---|---|---|---|---|
| Acadia NP | ME | 8.0 | 20.1 | 0.0 | -1.1 | 0.0 | -0.8 |
| Badlands NP | SD | 6.3 | 16.0 | -0.1 | -0.6 | -0.1 | -0.7 |
| Bandelier NM | NM | 4.2 | 11.1 | -0.1 | -0.3 | -0.1 | -0.4 |
| Big Bend NP | TX | 5.4 | 16.3 | -0.2 | -1.1 | -0.2 | -1.0 |
| Black Canyon of the Gunnison NM | CO | 2.3 | 9.5 | -0.1 | -0.1 | -0.1 | -0.1 |
| Bosque del Apache | NM | 5.6 | 13.0 | -0.1 | -0.6 | -0.1 | -0.6 |
| Boundary Waters Canoe Area | MN | 5.8 | 18.8 | -0.1 | -1.2 | -0.1 | -1.0 |
| Brigantine | NJ | 13.2 | 25.4 | -0.4 | -2.5 | -0.2 | -1.6 |
| Caney Creek Wilderness | AR | 11.3 | 24.4 | -0.4 | -3.2 | -0.6 | -2.2 |
| Carlsbad Caverns NP | TX | 5.2 | 15.5 | -0.1 | -0.9 | -0.1 | -0.8 |
| Cohutta Wilderness | GA | 12.9 | 26.6 | -0.8 | -3.8 | -0.5 | -2.3 |
| Dolly Sods Wilderness | WV | 10.3 | 27.1 | -1.1 | -5.7 | -0.8 | -3.2 |
| Eagles Nest Wilderness | CO | 0.4 | 8.3 | 0.0 | -0.1 | 0.0 | -0.1 |
| Everglades NP | FL | 11.5 | 20.4 | -0.3 | -1.0 | -0.3 | -0.7 |
| Flat Tops Wilderness | CO | 0.4 | 8.3 | 0.0 | -0.1 | 0.0 | -0.1 |
| Great Gulf Wilderness | NH | 6.7 | 19.2 | -0.1 | -1.8 | -0.1 | -1.3 |
| Great Sand Dunes NM | CO | 3.5 | 11.3 | -0.1 | -0.2 | -0.1 | -0.2 |
| Great Smoky Mountains NP | TN | 12.2 | 27.0 | -0.8 | -3.7 | -0.7 | -2.0 |
| Guadalupe Mountains NP | TX | 5.2 | 15.5 | -0.1 | -0.9 | -0.1 | -0.8 |
| Hercules-Glades Wilderness | MO | 12.2 | 25.2 | -0.6 | -2.5 | -0.8 | -1.7 |
| Isle Royale NP | MI | 6.4 | 19.9 | -0.1 | -1.0 | -0.2 | -0.9 |
| James River Face Wilderness | VA | 12.9 | 25.8 | -0.9 | -4.2 | -0.5 | -2.1 |
| Joyce-Kilmer-Slickrock Wilderness | TN | 12.2 | 27.0 | -0.8 | -3.7 | -0.7 | -2.0 |

| Class I Areas (IMPROVE Site) | State | 2014 Base Case Visibility 20% Best Days (dv) | 2014 Base Case Visibility 20% Worst Days (dv) | TR – 2014 Base Case 20% Best Days | TR – 2014 Base Case 20% Worst Days | BART – 2014 Base Case 20% Best Days | BART – 2014 Base Case 20% Worst Days |
|---|---|---|---|---|---|---|---|
| La Garita Wilderness | CO | 2.3 | 9.5 | -0.1 | -0.1 | -0.1 | -0.1 |
| Linville Gorge Wilderness | NC | 10.3 | 26.0 | -0.7 | -4.3 | -0.5 | -2.3 |
| Lostwood | ND | 7.9 | 18.8 | -0.1 | -0.5 | -0.1 | -0.5 |
| Lye Brook Wilderness | VT | 5.5 | 20.7 | -0.1 | -2.6 | -0.1 | -1.7 |
| Maroon Bells-Snowmass Wilderness | CO | 0.4 | 8.3 | 0.0 | -0.1 | 0.0 | -0.1 |
| Mammoth Cave NP | KY | 15.3 | 29.5 | -1.2 | -5.1 | -0.9 | -2.8 |
| Medicine Lake | MT | 6.5 | 17.7 | 0.0 | -0.3 | 0.0 | -0.3 |
| Mesa Verde NP | CO | 3.2 | 11.4 | -0.1 | -0.3 | -0.1 | -0.3 |
| Moosehorn | ME | 8.4 | 19.0 | 0.0* | -1.0 | 0.0* | -0.8 |
| Mount Zirkel Wilderness | CO | 1.0 | 9.2 | 0.0 | -0.1 | 0.0 | -0.1 |
| North Absaroka Wilderness | WY | 1.5 | 11.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Okefenokee | GA | 13.9 | 24.1 | -0.9 | -2.5 | -0.7 | -1.7 |
| Otter Creek Wilderness | WV | 10.3 | 27.1 | -1.1 | -5.7 | -0.8 | -3.2 |
| Pecos Wilderness | NM | 1.0 | 9.0 | -0.1 | -0.2 | -0.1 | -0.2 |
| Presidential Range-Dry River Wilderness | NH | 6.7 | 19.2 | -0.1 | -1.8 | -0.1 | -1.3 |
| Rawah Wilderness | CO | 1.0 | 9.2 | 0.0 | -0.1 | 0.0 | -0.1 |
| Roosevelt Campobello International Park | ME | 8.4 | 19.0 | 0.0* | -1.0 | 0.0* | -0.8 |
| Cape Romain | SC | 13.6 | 24.0 | -0.7 | -2.9 | -0.4 | -1.9 |
| Rocky Mountain NP | CO | 2.0 | 12.2 | 0.0 | -0.1 | 0.0 | -0.1 |
| Salt Creek | NM | 7.3 | 17.1 | -0.1 | -0.7 | -0.2 | -0.7 |
| San Pedro Parks Wilderness | NM | 1.2 | 9.9 | -0.2 | -0.3 | -0.2 | -0.4 |
| Seney | MI | 6.9 | 23.3 | -0.1 | -1.6 | 0.0 | -1.5 |
| Shenandoah NP | VA | 9.0 | 26.2 | -0.8 | -5.0 | -0.6 | -3.0 |
| Shining Rock Wilderness | NC | 6.3 | 24.8 | -0.7 | -3.8 | -0.5 | -2.1 |
| Sipsey Wilderness | AL | 14.5 | 26.5 | -0.9 | -3.7 | -0.9 | -2.1 |
| Theodore Roosevelt NP | ND | 6.8 | 17.0 | 0.0 | -0.3 | 0.0 | -0.4 |

| Class I Areas (IMPROVE Site) | State | 2014 Base Case Visibility 20% Best Days (dv) | 2014 Base Case Visibility 20% Worst Days (dv) | TR – 2014 Base Case 20% Best Days | TR – 2014 Base Case 20% Worst Days | BART – 2014 Base Case 20% Best Days | BART – 2014 Base Case 20% Worst Days |
|---|---|---|---|---|---|---|---|
| UL Bend | MT | 4.2 | 15.2 | 0.0 | -0.1 | 0.0 | -0.1 |
| Upper Buffalo Wilderness | AR | 11.3 | 24.7 | -0.5 | -2.5 | -0.6 | -1.4 |
| Voyageurs NP | MN | 6.6 | 18.4 | -0.1 | -1.0 | -0.1 | -0.8 |
| Washakie Wilderness | WY | 1.5 | 11.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| West Elk Wilderness | CO | 0.4 | 8.3 | 0.0 | -0.1 | 0.0 | -0.1 |
| Weminuche Wilderness | CO | 2.3 | 9.5 | -0.1 | -0.1 | -0.1 | -0.1 |
| White Mountain Wilderness | NM | 3.1 | 12.3 | -0.1 | -0.6 | -0.2 | -0.5 |
| Wheeler Peak Wilderness | NM | 1.0 | 9.0 | -0.1 | -0.2 | -0.1 | -0.2 |
| Wind Cave NP | SD | 4.6 | 15.1 | 0.0 | -0.3 | -0.1 | -0.4 |
| Wichita Mountains | OK | 9.1 | 21.7 | -0.2 | -1.6 | -0.2 | -1.2 |
| Wolf Island | GA | 13.9 | 24.1 | -0.9 | -2.5 | -0.7 | -1.7 |
| **Eastern Class I Areas Average (60 Areas)** | | | | **-0.3** | **-1.6** | **-0.2** | **-1.0** |
| Agua Tibia Wilderness | CA | 7.9 | 20.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Alpine Lake Wilderness | WA | 4.6 | 15.8 | 0.0* | 0.0 | 0.0* | 0.0 |
| Anaconda-Pintler Wilderness | MT | 2.3 | 16.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ansel Adams Wilderness (Minarets) | CA | 1.7 | 14.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Arches NP | UT | 2.6 | 9.8 | -0.1 | -0.2 | -0.1 | -0.2 |
| Mount Baldy Wilderness | AZ | 2.5 | 10.9 | -0.1 | 0.0* | -0.1 | -0.2 |
| Bob Marshall Wilderness | MT | 3.1 | 15.8 | 0.0 | -0.1 | 0.0 | -0.1 |
| Bryce Canyon NP | UT | 2.4 | 10.8 | 0.1# | -0.1 | 0.1# | -0.1 |
| Bridger Wilderness | WY | 1.6 | 10.4 | 0.0 | -0.1 | 0.0 | -0.1 |
| Cabinet Mountains Wilderness | MT | 3.0 | 14.0 | 0.0* | -0.1 | 0.0* | -0.1 |
| Canyonlands NP | UT | 2.6 | 9.8 | -0.1 | -0.2 | -0.1 | -0.2 |
| Capitol Reef NP | UT | 2.9 | 10.3 | 0.0 | -0.2 | 0.0 | -0.2 |
| Caribou Wilderness | CA | 2.3 | 13.2 | 0.0 | 0.0 | 0.0 | 0.0 |

| Class I Areas (IMPROVE Site) | State | 2014 Base Case Visibility 20% Best Days (dv) | 2014 Base Case Visibility 20% Worst Days (dv) | TR – 2014 Base Case 20% Best Days | TR – 2014 Base Case 20% Worst Days | BART – 2014 Base Case 20% Best Days | BART – 2014 Base Case 20% Worst Days |
|---|---|---|---|---|---|---|---|
| Chiricahua NM | AZ | 4.4 | 12.4 | -0.1 | -0.1 | -0.1 | -0.2 |
| Chiricahua Wilderness | AZ | 4.4 | 12.4 | -0.1 | -0.1 | -0.1 | -0.2 |
| Crater Lake NP | OR | 1.5 | 12.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Craters of the Moon NM | ID | 3.5 | 13.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cucamonga Wilderness | CA | 3.9 | 16.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Desolation Wilderness | CA | 2.1 | 12.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Diamond Peak Wilderness | OR | 1.5 | 12.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Eagle Cap Wilderness | OR | 3.5 | 16.9 | 0.0 | 0.0* | 0.0 | 0.0* |
| Emigrant Wilderness | CA | 3.1 | 16.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Fitzpatrick Wilderness | WY | 1.6 | 10.4 | 0.0 | -0.1 | 0.0 | -0.1 |
| Galiuro Wilderness | AZ | 4.4 | 12.4 | -0.1 | -0.1 | -0.1 | -0.2 |
| Gates of the Mountains Wilderness | MT | 1.2 | 11.6 | 0.0 | -0.1 | 0.0* | 0.0 |
| Gearhart Mountain Wilderness | OR | 1.5 | 12.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Gila Wilderness | NM | 2.9 | 13.0 | 0.0 | -0.2 | 0.0 | -0.3 |
| Glacier NP | MT | 6.8 | 19.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Glacier Peak Wilderness | WA | 2.9 | 12.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Goat Rocks Wilderness | WA | 1.5 | 11.9 | 0.0* | -0.1 | 0.0* | -0.1 |
| Grand Canyon NP | AZ | 1.9 | 11.0 | 0.0* | -0.1 | 0.0 | -0.1 |
| Grand Teton NP | WY | 2.0 | 10.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hells Canyon Wilderness | OR | 4.8 | 18.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hoover Wilderness | CA | 1.3 | 11.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jarbidge Wilderness | NV | 2.3 | 12.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| John Muir Wilderness | CA | 1.7 | 14.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Joshua Tree NM | CA | 5.5 | 17.3 | 0.0 | 0.0 | 0.1# | 0.0 |
| Kaiser Wilderness | CA | 1.7 | 14.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Kalmiopsis | OR | 6.1 | 16.1 | 0.0 | 0.0 | 0.0 | -0.1 |

| Class I Areas (IMPROVE Site) | State | 2014 Base Case Visibility 20% Best Days (dv) | 2014 Base Case Visibility 20% Worst Days (dv) | TR – 2014 Base Case 20% Best Days | TR – 2014 Base Case 20% Worst Days | BART – 2014 Base Case 20% Best Days | BART – 2014 Base Case 20% Worst Days |
|---|---|---|---|---|---|---|---|
| Wilderness | | | | | | | |
| Kings Canyon NP | CA | 7.6 | 21.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Lava Beds NM | CA | 2.9 | 13.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Lassen Volcanic NP | CA | 2.3 | 13.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mazatzal Wilderness | AZ | 5.0 | 12.9 | 0.0 | 0.2# | 0.0 | 0.2# |
| Mission Mountains Wilderness | MT | 3.1 | 15.8 | 0.0 | -0.1 | 0.0 | -0.1 |
| Mount Hood Wilderness | OR | 1.6 | 13.9 | 0.0 | -0.1 | 0.0 | -0.1 |
| Mount Jefferson Wilderness | OR | 2.6 | 15.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mokelumne Wilderness | CA | 2.1 | 12.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mountain Lakes Wilderness | OR | 1.5 | 12.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mount Rainier NP | WA | 4.8 | 16.0 | 0.0 | -0.1 | 0.0 | -0.1 |
| Mount Washington Wilderness | OR | 2.6 | 15.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| North Cascades NP | WA | 2.9 | 12.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Olympic NP | WA | 5.4 | 15.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Pasayten Wilderness | WA | 2.4 | 14.8 | 0.0 | -0.1 | 0.0 | -0.1 |
| Petrified Forest NP | AZ | 4.4 | 13.4 | 0.0 | 0.0 | -0.1 | -0.2 |
| Pine Mountain Wilderness | AZ | 5.0 | 12.9 | 0.0 | 0.2# | 0.0 | 0.2# |
| Pinnacles NM | CA | 7.8 | 16.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Point Reyes NS | CA | 9.0 | 21.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| San Rafael Wilderness | CA | 5.3 | 18.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Red Rock Lakes | WY | 2.0 | 10.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Redwood NP | CA | 5.8 | 18.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| San Gabriel Wilderness | CA | 3.9 | 16.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| San Gorgonio Wilderness | CA | 4.6 | 19.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Saguaro NM | AZ | 6.5 | 13.4 | -0.2 | 0.3# | -0.2 | -0.1 |
| San Jacinto Wilderness | CA | 4.6 | 19.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sawtooth Wilderness | ID | 3.6 | 14.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Scapegoat Wilderness | MT | 3.1 | 15.8 | 0.0 | -0.1 | 0.0 | -0.1 |

| Class I Areas (IMPROVE Site) | State | 2014 Base Case Visibility 20% Best Days (dv) | 2014 Base Case Visibility 20% Worst Days (dv) | TR – 2014 Base Case 20% Best Days | TR – 2014 Base Case 20% Worst Days | BART – 2014 Base Case 20% Best Days | BART – 2014 Base Case 20% Worst Days |
|---|---|---|---|---|---|---|---|
| Selway-Bitterroot Wilderness | MT | 2.3 | 16.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sequoia NP | CA | 7.6 | 21.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sierra Ancha Wilderness | AZ | 5.1 | 14.0 | -0.1 | 0.0 | 0.0 | 0.0 |
| South Warner Wilderness | CA | 2.9 | 13.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Strawberry Mountain Wilderness | OR | 3.5 | 16.9 | 0.0 | 0.0* | 0.0 | 0.0* |
| Superstition Wilderness | AZ | 5.5 | 13.5 | 0.0 | -0.1 | 0.0 | -0.1 |
| Sycamore Canyon Wilderness | AZ | 4.8 | 15.0 | 0.0 | -0.1 | 0.0 | -0.1 |
| Teton Wilderness | WY | 2.0 | 10.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Three Sisters Wilderness | OR | 2.6 | 15.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Thousand Lakes Wilderness | CA | 2.3 | 13.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ventana Wilderness | CA | 7.8 | 16.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mount Adams Wilderness | WA | 1.5 | 11.9 | 0.0* | -0.1 | 0.0* | -0.1 |
| Yellowstone NP | WY | 2.0 | 10.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Yosemite NP | CA | 3.1 | 16.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| **All Class I Areas Average (140 Areas)** | | | | **-0.1** | **-0.7** | **-0.1** | **-0.5** |

**Notes:** Negative numbers indicate visibility improvement.

* The result at these Class I areas was a degradation of less than 0.05 deciviews, which when rounded equals 0.0.

# The default visibility test at these areas resulted in visibility degradation. See Appendix B for more information on why we do not believe that visibility degradation will actually occur in these areas. The values shown in this table were used (before rounding) to calculate the eastern and national averages.

A summary of the results of the second prong of the test for the Transport Rule and national regions under each control scenario is shown below in Table 3-6.

**Table 3-6.** Summary of average visibility results for Eastern and nationwide areas.

| | Transport Rule – 2014 Base Case 20% Best Days | Transport Rule – 2014 Base Case 20% Worst Days | Nationwide BART – 2014 Base Case 20% Best Days | Nationwide BART – 2014 Base Case 20% Worst Days |
|---|---|---|---|---|
| **Eastern Class I Areas Average (60 Areas)** | **-0.3** | **-1.6** | **-0.2** | **-1.0** |
| **All Class I Areas Average (140 Areas)** | **-0.1** | **-0.7** | **-0.1** | **-0.5** |

For the 60 Eastern Class I areas analyzed, the average visibility improvement from 2014 baseline (on the 20 percent worst days) expected as a result of the Transport Rule + BART-elsewhere is 1.6 deciviews (dv), and the average degree of improvement from 2014 baseline predicted for nationwide BART is 1.0 dv. The average visibility improvement from 2014 baseline on the 20 percent best days expected as a result of the Transport Rule + BART-elsewhere is 0.3 deciviews (dv), and the average degree of improvement from 2014 baseline predicted for nationwide BART is 0.2 dv. Therefore, the Transport Rule makes substantially more improvement than nationwide BART in the East.

Similarly, for Class I Areas nationwide, the visibility modeling shows that for the 140 class I areas evaluated, the average visibility improvement, on the 20 percent worst days in 2014 was 0.7 dv under the Transport Rule, and 0.5 dv under the nationwide BART approach. The average visibility improvement, on the 20 percent best days in 2014 was 0.1 dv for "Transport Rule + BART-elsewhere" and 0.1 dv under "nationwide BART"[30].

Based on these results, the Transport Rule scenario passes the second prong of the proposed better-than-BART test based on the fact that, on average, in both the Eastern Class I areas and nationally, visibility improvement is greater under the Transport Rule + BART-elsewhere scenario compared to nationwide BART on the 20% best and 20% worst visibility days.

[30] Before rounding to the tenths digit, "Transport Rule +BART-elsewhwere" has a visibility improvement of 0.13 dv compared to 0.11 dv for "nationwide BART".

### 3.6.3 Summary of Better than BART Test

The Transport Rule scenario passes the first prong of the two-pronged better-than-BART test by not causing degradation of visibility at any Class I area on either the 20% best or 20% worst visibility days. The Transport Rule also passes the second prong of the better-than-BART test based on the expectation that :(a) for the Eastern Class I areas visibility improvement is greater on average for the both the 20% best and 20% worst days under the Transport Rule compared to nationwide BART, and (b) for all Class I areas nationally, visibility improvement is essentially equal on the best 20% days, and greater on the worst 20% days.[31]

[31] Under the Regional Haze Rule, reasonable progress goals are defined in terms of improvement on the worst 20% days, and no degradation on the 20% best days. The proposed better-than-BART test does not specify whether each prong should apply on both best and worst days. For purposes of this analysis, as previously noted, we have considered both the best days and the worst days under both the no-degradation prong and the overall-improvement prong, without determining that all subsequent better-than-BART demonstrations must do so. Similarly, the fact that we have considered all Class I areas nationwide in part of our analysis does not imply that any future better-than-BART demonstration must necessarily consider all Class I areas in the nation to be "impacted" by the particular BART-alternative under consideration.

# Appendix A

## EGUs that were assumed to BART-subject for the purpose of this analysis

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Alabama | Barry | 4 | 362 | 1969 |
| Alabama | Barry | 5 | 750 | 1971 |
| Alabama | Charles R Lowman | 1 | 86.0 | 1969 |
| Alabama | Charles R Lowman | 2 | 238 | 1979 |
| Alabama | Charles R Lowman | 3 | 238 | 1980 |
| Alabama | Colbert | 5 | 459 | 1965 |
| Alabama | E C Gaston | 4 | 256 | 1962 |
| Alabama | E C Gaston | 5 | 861 | 1974 |
| Alabama | Gorgas | 10 | 690 | 1972 |
| Alabama | Greene County | 1 | 254 | 1965 |
| Alabama | Greene County | 2 | 243 | 1966 |
| Alabama | James H Miller Jr | 2 | 687 | 1985 |
| Alabama | James H Miller Jr | 1 | 684 | 1978 |
| Alabama | Widows Creek | 8 | 464 | 1965 |
| Arizona | Apache Station | 2 | 175 | 1979 |
| Arizona | Apache Station | 3 | 175 | 1979 |
| Arizona | Cholla | 2 | 275 | 1978 |
| Arizona | Cholla | 3 | 271 | 1980 |
| Arizona | Cholla | 4 | 380 | 1981 |
| Arizona | Coronado | U1B | 395 | 1979 |
| Arizona | Coronado | U2B | 390 | 1980 |
| Arizona | H Wilson Sundt Generating Station | 4 | 156 | 1967 |
| Arizona | Navajo | 1 | 750 | 1974 |
| Arizona | Navajo | 2 | 750 | 1975 |
| Arizona | Navajo | 3 | 750 | 1976 |
| Arkansas | Flint Creek | 1 | 528 | 1978 |
| Arkansas | White Bluff | 1 | 815 | 1980 |
| Arkansas | White Bluff | 2 | 825 | 1981 |
| Colorado | Cherokee | 3 | 165 | 1962 |
| Colorado | Cherokee | 4 | 388 | 1968 |
| Colorado | Comanche | 1 | 366 | 1973 |
| Colorado | Comanche | 2 | 370 | 1975 |
| Colorado | Craig | C1 | 428 | 1980 |
| Colorado | Craig | C2 | 428 | 1979 |
| Colorado | Hayden | H1 | 205 | 1965 |
| Colorado | Hayden | H2 | 300 | 1976 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Colorado | Martin Drake | 5 | 46.0 | 1962 |
| Colorado | Martin Drake | 6 | 77.0 | 1968 |
| Colorado | Martin Drake | 7 | 131 | 1974 |
| Colorado | Pawnee | 1 | 505 | 1981 |
| Colorado | Ray D Nixon | 1 | 208 | 1980 |
| Colorado | Valmont | 5 | 199 | 1964 |
| Connecticut | Bridgeport Station | BHB3 | 372 | 1968 |
| Delaware | Edge Moor | 4 | 174 | 1966 |
| Delaware | Indian River Generating Station | 3 | 153 | 1970 |
| Delaware | Indian River Generating Station | 4 | 405 | 1980 |
| Florida | Big Bend | BB01 | 391 | 1970 |
| Florida | Big Bend | BB02 | 391 | 1973 |
| Florida | Big Bend | BB03 | 364 | 1976 |
| Florida | Crist | 6 | 302 | 1970 |
| Florida | Crist | 7 | 472 | 1973 |
| Florida | Crystal River | 1 | 379 | 1966 |
| Florida | Crystal River | 2 | 491 | 1969 |
| Florida | Crystal River | 4 | 722 | 1982 |
| Florida | Crystal River | 5 | 721 | 1984 |
| Florida | Deerhaven Generating Station | B2 | 228 | 1981 |
| Florida | Lansing Smith | 1 | 162 | 1965 |
| Florida | Lansing Smith | 2 | 195 | 1967 |
| Georgia | Bowen | 1BLR | 713 | 1971 |
| Georgia | Bowen | 2BLR | 718 | 1972 |
| Georgia | Bowen | 3BLR | 902 | 1974 |
| Georgia | Bowen | 4BLR | 929 | 1975 |
| Georgia | Hammond | 4 | 510 | 1970 |
| Georgia | Harllee Branch | 1 | 266 | 1965 |
| Georgia | Harllee Branch | 2 | 325 | 1967 |
| Georgia | Harllee Branch | 3 | 509 | 1968 |
| Georgia | Harllee Branch | 4 | 507 | 1969 |
| Georgia | Jack McDonough | MB1 | 258 | 1963 |
| Georgia | Jack McDonough | MB2 | 259 | 1964 |
| Georgia | Kraft | 3 | 102 | 1965 |
| Georgia | McIntosh | 1 | 157 | 1979 |
| Georgia | Scherer | 1 | 837 | 1982 |
| Georgia | Scherer | 2 | 843 | 1984 |
| Georgia | Wansley | 1 | 891 | 1976 |
| Georgia | Wansley | 2 | 892 | 1978 |
| Georgia | Yates | Y6BR | 352 | 1974 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Georgia | Yates | Y7BR | 355 | 1974 |
| Illinois | Baldwin Energy Complex | 1 | 624 | 1970 |
| Illinois | Baldwin Energy Complex | 2 | 629 | 1973 |
| Illinois | Baldwin Energy Complex | 3 | 629 | 1975 |
| Illinois | Coffeen | 01 | 340 | 1965 |
| Illinois | Coffeen | 02 | 560 | 1972 |
| Illinois | Dallman | 31 | 86.0 | 1968 |
| Illinois | Dallman | 32 | 87.0 | 1972 |
| Illinois | Dallman | 33 | 199 | 1978 |
| Illinois | Duck Creek | 1 | 335 | 1976 |
| Illinois | E D Edwards | 2 | 273 | 1968 |
| Illinois | E D Edwards | 3 | 364 | 1972 |
| Illinois | Havana | 9 | 487 | 1978 |
| Illinois | Joliet 29 | 71 | 259 | 1965 |
| Illinois | Joliet 29 | 72 | 259 | 1965 |
| Illinois | Joliet 29 | 81 | 259 | 1965 |
| Illinois | Joliet 29 | 82 | 259 | 1965 |
| Illinois | Kincaid Generation LLC | 1 | 584 | 1967 |
| Illinois | Kincaid Generation LLC | 2 | 584 | 1968 |
| Illinois | Marion | 4 | 170 | 1978 |
| Illinois | Marion | 123 | 120 | 2003 |
| Illinois | Newton | 1 | 557 | 1977 |
| Illinois | Newton | 2 | 569 | 1982 |
| Illinois | Pearl Station | 1A | 22.0 | 1967 |
| Illinois | Powerton | 51 | 385 | 1972 |
| Illinois | Powerton | 52 | 385 | 1972 |
| Illinois | Powerton | 61 | 385 | 1975 |
| Illinois | Powerton | 62 | 385 | 1975 |
| Illinois | Waukegan | 8 | 361 | 1962 |
| Illinois | Will County | 4 | 510 | 1963 |
| Illinois | Wood River | 5 | 383 | 1964 |
| Indiana | A B Brown | 1 | 245 | 1979 |
| Indiana | Bailly | 7 | 160 | 1962 |
| Indiana | Bailly | 8 | 320 | 1968 |
| Indiana | Cayuga | 1 | 479 | 1970 |
| Indiana | Cayuga | 2 | 473 | 1972 |
| Indiana | Crawfordsville | 6 | 12.6 | 1965 |
| Indiana | Dean H Mitchell | 11 | 110 | 1970 |
| Indiana | F B Culley | 2 | 90.0 | 1966 |
| Indiana | F B Culley | 3 | 270 | 1973 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Indiana | Frank E Ratts | 1SG1 | 122 | 1970 |
| Indiana | Frank E Ratts | 2SG1 | 121 | 1970 |
| Indiana | Gibson | 1 | 630 | 1975 |
| Indiana | Gibson | 2 | 628 | 1975 |
| Indiana | Gibson | 3 | 628 | 1978 |
| Indiana | Gibson | 4 | 622 | 1979 |
| Indiana | Harding Street | 70 | 435 | 1973 |
| Indiana | Jasper 2 | 1 | 14.0 | 1968 |
| Indiana | Logansport | 6 | 22.0 | 1964 |
| Indiana | Merom | 1SG1 | 507 | 1983 |
| Indiana | Merom | 2SG1 | 493 | 1982 |
| Indiana | Michigan City | 12 | 469 | 1974 |
| Indiana | Petersburg | 1 | 232 | 1967 |
| Indiana | Petersburg | 2 | 435 | 1969 |
| Indiana | Petersburg | 3 | 540 | 1977 |
| Indiana | R M Schahfer | 14 | 431 | 1976 |
| Indiana | R M Schahfer | 15 | 472 | 1979 |
| Indiana | State Line | 4 | 303 | 1962 |
| Indiana | Tanners Creek | U4 | 500 | 1964 |
| Indiana | Wabash River | 6 | 318 | 1968 |
| Indiana | Warrick | 2 | 136 | 1964 |
| Indiana | Warrick | 3 | 136 | 1965 |
| Indiana | Warrick | 4 | 300 | 1970 |
| Indiana | Whitewater Valley | 2 | 62.8 | 1973 |
| Iowa | Ames Electric Services Power Plant | 7 | 33.0 | 1968 |
| Iowa | Burlington | 1 | 209 | 1968 |
| Iowa | Fair Station | 2 | 41.0 | 1967 |
| Iowa | George Neal North | 1 | 135 | 1964 |
| Iowa | George Neal North | 2 | 300 | 1972 |
| Iowa | George Neal North | 3 | 515 | 1975 |
| Iowa | George Neal South | 4 | 632 | 1979 |
| Iowa | Lansing | 4 | 261 | 1977 |
| Iowa | Milton L Kapp | 2 | 211 | 1967 |
| Iowa | Muscatine Plant #1 | 8 | 35.0 | 1969 |
| Iowa | Ottumwa | 1 | 673 | 1981 |
| Iowa | Pella | 6 | 15.0 | 1974 |
| Iowa | Pella | 7 | 12.8 | 1964 |
| Iowa | Prairie Creek | 4 | 125 | 1967 |
| Iowa | Streeter Station | 6 | 18.9 | 1963 |
| Iowa | Streeter Station | 7 | 35.8 | 1973 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Iowa | Walter Scott Jr. Energy Center | 3 | 690 | 1978 |
| Kansas | Jeffrey Energy Center | 1 | 730 | 1978 |
| Kansas | Jeffrey Energy Center | 2 | 730 | 1980 |
| Kansas | La Cygne | 1 | 724 | 1973 |
| Kansas | La Cygne | 2 | 682 | 1977 |
| Kansas | Lawrence Energy Center | 5 | 366 | 1971 |
| Kansas | Nearman Creek | N1 | 229 | 1981 |
| Kansas | Quindaro | 1 | 72.0 | 1965 |
| Kansas | Quindaro | 2 | 111 | 1971 |
| Kansas | Tecumseh Energy Center | 10 | 129 | 1962 |
| Kentucky | Big Sandy | BSU1 | 260 | 1963 |
| Kentucky | Big Sandy | BSU2 | 800 | 1969 |
| Kentucky | Cane Run | 4 | 155 | 1962 |
| Kentucky | Cane Run | 5 | 168 | 1966 |
| Kentucky | Cane Run | 6 | 240 | 1969 |
| Kentucky | Cooper | 1 | 116 | 1965 |
| Kentucky | Cooper | 2 | 225 | 1969 |
| Kentucky | E W Brown | 2 | 160 | 1963 |
| Kentucky | E W Brown | 3 | 422 | 1971 |
| Kentucky | East Bend | 2 | 600 | 1981 |
| Kentucky | Elmer Smith | 1 | 132 | 1964 |
| Kentucky | Elmer Smith | 2 | 261 | 1974 |
| Kentucky | Ghent | 1 | 475 | 1973 |
| Kentucky | Ghent | 2 | 469 | 1977 |
| Kentucky | Ghent | 3 | 478 | 1981 |
| Kentucky | H L Spurlock | 1 | 315 | 1977 |
| Kentucky | H L Spurlock | 2 | 509 | 1981 |
| Kentucky | HMP&L Station Two Henderson | H1 | 153 | 1973 |
| Kentucky | HMP&L Station Two Henderson | H2 | 159 | 1974 |
| Kentucky | Kenneth C Coleman | C1 | 150 | 1969 |
| Kentucky | Kenneth C Coleman | C2 | 150 | 1970 |
| Kentucky | Kenneth C Coleman | C3 | 155 | 1971 |
| Kentucky | Mill Creek | 1 | 303 | 1972 |
| Kentucky | Mill Creek | 2 | 301 | 1974 |
| Kentucky | Mill Creek | 3 | 391 | 1978 |
| Kentucky | Mill Creek | 4 | 477 | 1982 |
| Kentucky | Paradise | 1 | 616 | 1963 |
| Kentucky | Paradise | 2 | 602 | 1963 |
| Kentucky | Paradise | 3 | 977 | 1970 |
| Kentucky | R D Green | G1 | 231 | 1979 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Kentucky | R D Green | G2 | 233 | 1981 |
| Kentucky | Robert A Reid | R1 | 65.0 | 1966 |
| Louisiana | Big Cajun 2 | 2B1 | 580 | 1981 |
| Louisiana | Big Cajun 2 | 2B1 | 580 | 1981 |
| Louisiana | R S Nelson | 6 | 550 | 1982 |
| Louisiana | Rodemacher | 2 | 523 | 1982 |
| Maryland | C P Crane | 2 | 200 | 1963 |
| Maryland | Chalk Point LLC | 1 | 341 | 1964 |
| Maryland | Chalk Point LLC | 2 | 342 | 1965 |
| Maryland | Dickerson | 3 | 182 | 1962 |
| Maryland | Herbert A Wagner | 3 | 324 | 1966 |
| Maryland | Morgantown Generating Plant | 1 | 624 | 1970 |
| Maryland | Morgantown Generating Plant | 2 | 620 | 1971 |
| Massachusetts | Brayton Point | 1 | 243 | 1963 |
| Massachusetts | Brayton Point | 2 | 244 | 1964 |
| Massachusetts | Brayton Point | 3 | 612 | 1969 |
| Michigan | Belle River | 1 | 698 | 1984 |
| Michigan | Belle River | 2 | 698 | 1985 |
| Michigan | Eckert Station | 4 | 69.2 | 1964 |
| Michigan | Eckert Station | 5 | 68.9 | 1968 |
| Michigan | Eckert Station | 6 | 66.8 | 1970 |
| Michigan | Erickson Station | 1 | 152 | 1973 |
| Michigan | Harbor Beach | 1 | 103 | 1968 |
| Michigan | J H Campbell | 1 | 260 | 1962 |
| Michigan | J H Campbell | 2 | 355 | 1967 |
| Michigan | J H Campbell | 3 | 825 | 1980 |
| Michigan | James De Young | 4 | 20.5 | 1962 |
| Michigan | James De Young | 5 | 27.0 | 1969 |
| Michigan | Monroe | 1 | 770 | 1972 |
| Michigan | Monroe | 2 | 785 | 1973 |
| Michigan | Monroe | 3 | 795 | 1973 |
| Michigan | Monroe | 4 | 775 | 1974 |
| Michigan | Presque Isle | 5 | 88.0 | 1974 |
| Michigan | Presque Isle | 6 | 88.0 | 1975 |
| Michigan | Presque Isle | 7 | 85.0 | 1978 |
| Michigan | Presque Isle | 8 | 85.0 | 1978 |
| Michigan | Presque Isle | 9 | 85.0 | 1979 |
| Michigan | Shiras | 2 | 19.5 | 1972 |
| Michigan | St Clair | 7 | 440 | 1969 |
| Michigan | Trenton Channel | 9A | 536 | 1968 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Minnesota | Allen S King | 1 | 610 | 1968 |
| Minnesota | Austin Northeast | NEPP | 29.3 | 1971 |
| Minnesota | Clay Boswell | 3 | 351 | 1973 |
| Minnesota | Clay Boswell | 4 | 525 | 1980 |
| Minnesota | Hibbing | 1 | 10.2 | 1965 |
| Minnesota | Hibbing | 2 | 10.2 | 1965 |
| Minnesota | Hibbing | 3 | 10.2 | 1965 |
| Minnesota | Hoot Lake | 3 | 84.0 | 1964 |
| Minnesota | Sherburne County | 1 | 762 | 1976 |
| Minnesota | Sherburne County | 2 | 752 | 1977 |
| Minnesota | Silver Bay Power | BLR2 | 69.0 | 1963 |
| Minnesota | Silver Lake | 3 | 24.3 | 1962 |
| Minnesota | Silver Lake | 4 | 59.2 | 1969 |
| Minnesota | Taconite Harbor Energy Center | 3 | 68.0 | 1967 |
| Mississippi | Henderson | H3 | 17.9 | 1967 |
| Mississippi | Jack Watson | 4 | 230 | 1968 |
| Mississippi | Jack Watson | 5 | 476 | 1973 |
| Mississippi | R D Morrow | 1 | 180 | 1978 |
| Mississippi | R D Morrow | 2 | 180 | 1978 |
| Mississippi | Victor J Daniel Jr | 1 | 514 | 1977 |
| Mississippi | Victor J Daniel Jr | 2 | 514 | 1981 |
| Missouri | Asbury | 1 | 213 | 1970 |
| Missouri | Blue Valley | 3 | 51.0 | 1965 |
| Missouri | Iatan | 1 | 651 | 1980 |
| Missouri | James River Power Station | 4 | 56.0 | 1964 |
| Missouri | James River Power Station | 5 | 97.0 | 1970 |
| Missouri | Labadie | 1 | 597 | 1970 |
| Missouri | Labadie | 2 | 594 | 1971 |
| Missouri | Labadie | 3 | 612 | 1972 |
| Missouri | Labadie | 4 | 612 | 1973 |
| Missouri | Lake Road | 6 | 97.4 | 1967 |
| Missouri | Marshall | 5 | 16.0 | 1967 |
| Missouri | Montrose | 3 | 176 | 1964 |
| Missouri | New Madrid | 1 | 580 | 1972 |
| Missouri | New Madrid | 2 | 580 | 1977 |
| Missouri | Rush Island | 1 | 604 | 1976 |
| Missouri | Rush Island | 2 | 604 | 1977 |
| Missouri | Sibley | 2 | 53.9 | 1962 |
| Missouri | Sibley | 3 | 401 | 1969 |
| Missouri | Sikeston Power Station | 1 | 233 | 1981 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Missouri | Sioux | 1 | 497 | 1967 |
| Missouri | Sioux | 2 | 497 | 1968 |
| Missouri | Southwest Power Station | 1 | 178 | 1976 |
| Missouri | Thomas Hill | MB1 | 175 | 1966 |
| Missouri | Thomas Hill | MB2 | 275 | 1969 |
| Montana | Colstrip | 1 | 307 | 1975 |
| Montana | Colstrip | 2 | 307 | 1976 |
| Montana | J E Corette Plant | 2 | 158 | 1968 |
| Nebraska | Gerald Gentleman[32] | 1 | 665 | 1979 |
| Nebraska | Lon Wright | 7 | 20.0 | 1963 |
| Nebraska | Lon Wright | 8 | 85.0 | 1976 |
| Nebraska | Nebraska City | 1 | 646 | 1979 |
| Nebraska | North Omaha | 4 | 138 | 1963 |
| Nebraska | North Omaha | 5 | 224 | 1968 |
| Nebraska | Sheldon | 1 | 105 | 1968 |
| Nebraska | Whelan Energy Center | 1 | 77.0 | 1981 |
| Nevada | Reid Gardner | 1 | 110 | 1965 |
| Nevada | Reid Gardner | 2 | 110 | 1968 |
| Nevada | Reid Gardner | 3 | 110 | 1976 |
| New Hampshire | Merrimack | 2 | 320 | 1968 |
| New Jersey | PSEG Hudson Generating Station | 2 | 608 | 1967 |
| New Mexico | Four Corners | 1 | 170 | 1963 |
| New Mexico | Four Corners | 2 | 170 | 1963 |
| New Mexico | Four Corners | 3 | 220 | 1964 |
| New Mexico | Four Corners | 4 | 760 | 1969 |
| New Mexico | Four Corners | 5 | 760 | 1970 |
| New Mexico | San Juan | 1 | 322 | 1976 |
| New Mexico | San Juan | 2 | 320 | 1973 |
| New Mexico | San Juan | 3 | 495 | 1979 |
| New Mexico | San Juan | 4 | 506 | 1982 |
| North Carolina | Asheville | 1 | 191 | 1964 |
| North Carolina | Asheville | 2 | 185 | 1971 |
| North Carolina | Belews Creek | 1 | 1115 | 1974 |
| North Carolina | Belews Creek | 2 | 1115 | 1975 |
| North Carolina | Cliffside | 5 | 550 | 1972 |
| North Carolina | L V Sutton | 3 | 403 | 1972 |

[32] Gerald Gentleman Unit 2 was inadvertently omitted from the BART inventory. See Table 2-4 for information on how this omission potentially affected total $SO_2$ emissions the "Nationwide BART" control scenario. Total NOx emissions would not have been impacted.

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| North Carolina | Lee | 3 | 248 | 1962 |
| North Carolina | Marshall | 1 | 378 | 1965 |
| North Carolina | Marshall | 2 | 378 | 1966 |
| North Carolina | Marshall | 3 | 657 | 1969 |
| North Carolina | Marshall | 4 | 657 | 1970 |
| North Carolina | Roxboro | 1 | 369 | 1966 |
| North Carolina | Roxboro | 2 | 671 | 1968 |
| North Carolina | Roxboro | 3A | 353 | 1973 |
| North Carolina | Roxboro | 3B | 353 | 1973 |
| North Carolina | Roxboro | 4A | 349 | 1980 |
| North Carolina | Roxboro | 4B | 349 | 1980 |
| North Dakota | Coal Creek | 1 | 554 | 1979 |
| North Dakota | Coal Creek | 2 | 560 | 1981 |
| North Dakota | Leland Olds | 1 | 221 | 1966 |
| North Dakota | Leland Olds | 2 | 448 | 1975 |
| North Dakota | Milton R Young | B1 | 250 | 1970 |
| North Dakota | Milton R Young | B2 | 455 | 1977 |
| North Dakota | R M Heskett | B2 | 75.5 | 1963 |
| North Dakota | Stanton | 1 | 130 | 1967 |
| Ohio | Avon Lake | 12 | 616 | 1970 |
| Ohio | Bay Shore | 3 | 142 | 1963 |
| Ohio | Bay Shore | 4 | 215 | 1968 |
| Ohio | Cardinal | 1 | 600 | 1967 |
| Ohio | Cardinal | 2 | 600 | 1967 |
| Ohio | Cardinal | 3 | 630 | 1977 |
| Ohio | Conesville | 3 | 165 | 1962 |
| Ohio | Conesville | 4 | 780 | 1973 |
| Ohio | Conesville | 5 | 375 | 1976 |
| Ohio | Conesville | 6 | 375 | 1978 |
| Ohio | Dover | 4 | 15.2 | 1968 |
| Ohio | Eastlake | 5 | 597 | 1972 |
| Ohio | General James M Gavin | 1 | 1310 | 1974 |
| Ohio | General James M Gavin | 2 | 1300 | 1975 |
| Ohio | Hamilton | 8 | 32.8 | 1964 |
| Ohio | Hamilton | 9 | 51.0 | 1974 |
| Ohio | J M Stuart | 1 | 597 | 1971 |
| Ohio | J M Stuart | 2 | 597 | 1970 |
| Ohio | J M Stuart | 3 | 597 | 1972 |
| Ohio | J M Stuart | 4 | 597 | 1974 |
| Ohio | Lake Road | 11 | 20.0 | 1967 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Ohio | Lake Shore | 18 | 245 | 1962 |
| Ohio | Miami Fort | 7 | 500 | 1975 |
| Ohio | Miami Fort | 8 | 500 | 1978 |
| Ohio | Muskingum River | 5 | 585 | 1968 |
| Ohio | Orrville | 13 | 23.0 | 1971 |
| Ohio | Shelby Municipal Light Plant | 1 | 12.0 | 1968 |
| Ohio | Shelby Municipal Light Plant | 2 | 12.0 | 1968 |
| Ohio | St Marys | 6 | 9.00 | 1967 |
| Ohio | W H Sammis | 4 | 180 | 1962 |
| Ohio | W H Sammis | 5 | 300 | 1967 |
| Ohio | W H Sammis | 6 | 600 | 1969 |
| Ohio | W H Sammis | 7 | 600 | 1971 |
| Ohio | Walter C Beckjord | 5 | 238 | 1962 |
| Ohio | Walter C Beckjord | 6 | 414 | 1969 |
| Oklahoma | Muskogee | 4 | 511 | 1977 |
| Oklahoma | Muskogee | 5 | 522 | 1978 |
| Oklahoma | Northeastern | 3313 | 450 | 1979 |
| Oklahoma | Northeastern | 3314 | 450 | 1980 |
| Oklahoma | Sooner | 1 | 535 | 1979 |
| Oklahoma | Sooner | 2 | 540 | 1980 |
| Oregon | Boardman | 1SG | 585 | 1980 |
| Pennsylvania | Bruce Mansfield | 1 | 830 | 1976 |
| Pennsylvania | Bruce Mansfield | 2 | 830 | 1977 |
| Pennsylvania | Bruce Mansfield | 3 | 830 | 1979 |
| Pennsylvania | Cheswick | 1 | 580 | 1970 |
| Pennsylvania | Conemaugh | 1 | 850 | 1970 |
| Pennsylvania | Conemaugh | 2 | 850 | 1971 |
| Pennsylvania | Hatfields Ferry Power Station | 1 | 530 | 1969 |
| Pennsylvania | Hatfields Ferry Power Station | 2 | 530 | 1970 |
| Pennsylvania | Hatfields Ferry Power Station | 3 | 530 | 1971 |
| Pennsylvania | Homer City Station | 1 | 620 | 1969 |
| Pennsylvania | Homer City Station | 2 | 614 | 1970 |
| Pennsylvania | Homer City Station | 3 | 650 | 1977 |
| Pennsylvania | Keystone | 1 | 850 | 1967 |
| Pennsylvania | Keystone | 2 | 850 | 1968 |
| Pennsylvania | Mitchell Power Station | 33 | 277 | 1963 |
| Pennsylvania | New Castle | 5 | 138 | 1964 |
| Pennsylvania | Portland | 2 | 243 | 1962 |
| Pennsylvania | PPL Brunner Island | 2 | 387 | 1965 |
| Pennsylvania | PPL Brunner Island | 3 | 754 | 1981 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Pennsylvania | PPL Montour | 1 | 761 | 1971 |
| Pennsylvania | PPL Montour | 2 | 757 | 1973 |
| South Carolina | Canadys Steam | CAN1 | 105 | 1962 |
| South Carolina | Canadys Steam | CAN2 | 116 | 1964 |
| South Carolina | Canadys Steam | CAN3 | 175 | 1967 |
| South Carolina | Dolphus M Grainger | 1 | 85.0 | 1966 |
| South Carolina | Dolphus M Grainger | 2 | 85.0 | 1966 |
| South Carolina | Jefferies | 3 | 153 | 1970 |
| South Carolina | Jefferies | 4 | 153 | 1970 |
| South Carolina | Wateree | WAT1 | 350 | 1970 |
| South Carolina | Wateree | WAT2 | 350 | 1971 |
| South Carolina | Williams | WIL1 | 615 | 1973 |
| South Carolina | Winyah | 1 | 295 | 1975 |
| South Carolina | Winyah | 2 | 295 | 1977 |
| South Dakota | Big Stone | 1 | 470 | 1975 |
| Tennessee | Bull Run | 1 | 881 | 1967 |
| Tennessee | Cumberland | 1 | 1232 | 1973 |
| Tennessee | Cumberland | 2 | 1233 | 1973 |
| Texas | Big Brown | 1 | 575 | 1971 |
| Texas | Big Brown | 2 | 575 | 1972 |
| Texas | Coleto Creek | 1 | 632 | 1980 |
| Texas | Fayette Power Project | 1 | 598 | 1979 |
| Texas | Fayette Power Project | 2 | 598 | 1980 |
| Texas | Harrington | 061B | 347 | 1976 |
| Texas | Harrington | 062B | 347 | 1978 |
| Texas | Harrington | 063B | 347 | 1980 |
| Texas | J T Deely | 1 | 385 | 1977 |
| Texas | J T Deely | 2 | 385 | 1978 |
| Texas | Martin Lake | 1 | 750 | 1977 |
| Texas | Martin Lake | 2 | 750 | 1978 |
| Texas | Martin Lake | 3 | 750 | 1979 |
| Texas | Monticello | 1 | 565 | 1974 |
| Texas | Monticello | 2 | 565 | 1975 |
| Texas | Monticello | 3 | 750 | 1978 |
| Texas | Sandow | 4 | 545 | 1981 |
| Texas | W A Parish | WAP5 | 645 | 1977 |
| Texas | W A Parish | WAP6 | 650 | 1978 |
| Texas | W A Parish | WAP7 | 565 | 1980 |
| Texas | Welsh | 1 | 528 | 1977 |
| Texas | Welsh | 2 | 528 | 1980 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Utah | Hunter | 1 | 430 | 1978 |
| Utah | Hunter | 2 | 430 | 1980 |
| Utah | Huntington | 1 | 445 | 1977 |
| Utah | Huntington | 2 | 450 | 1974 |
| Virginia | Chesapeake | 4 | 217 | 1962 |
| Virginia | Chesterfield | 5 | 310 | 1964 |
| Virginia | Chesterfield | 6 | 658 | 1969 |
| Washington | Transalta Centralia Generation | BW21 | 703 | 1972 |
| Washington | Transalta Centralia Generation | BW22 | 703 | 1973 |
| West Virginia | Fort Martin Power Station | 1 | 552 | 1967 |
| West Virginia | Fort Martin Power Station | 2 | 555 | 1968 |
| West Virginia | Harrison Power Station | 1 | 652 | 1972 |
| West Virginia | Harrison Power Station | 2 | 642 | 1973 |
| West Virginia | Harrison Power Station | 3 | 651 | 1974 |
| West Virginia | John E Amos | 1 | 800 | 1971 |
| West Virginia | John E Amos | 2 | 800 | 1972 |
| West Virginia | John E Amos | 3 | 1300 | 1973 |
| West Virginia | Mitchell | 1 | 800 | 1971 |
| West Virginia | Mitchell | 2 | 800 | 1971 |
| West Virginia | Mountaineer | 1 | 1300 | 1980 |
| West Virginia | Mt Storm | 1 | 524 | 1965 |
| West Virginia | Mt Storm | 2 | 524 | 1966 |
| West Virginia | Mt Storm | 3 | 521 | 1973 |
| West Virginia | Pleasants Power Station | 1 | 639 | 1979 |
| West Virginia | Pleasants Power Station | 2 | 639 | 1980 |
| Wisconsin | Capitol Heat and Power | 1 | 0.9 | 1963 |
| Wisconsin | Capitol Heat and Power | 2 | 1 | 1964 |
| Wisconsin | Columbia | 1 | 555 | 1975 |
| Wisconsin | Columbia | 2 | 559 | 1978 |
| Wisconsin | Edgewater | 4 | 321 | 1969 |
| Wisconsin | Genoa | 1 | 356 | 1969 |
| Wisconsin | John P Madgett | B1 | 398 | 1978 |
| Wisconsin | Manitowoc | 7 | 18.0 | 1964 |
| Wisconsin | Menasha | B24 | 14.5 | 1964 |
| Wisconsin | Nelson Dewey | 2 | 111 | 1962 |
| Wisconsin | Pleasant Prairie | 1 | 617 | 1980 |
| Wisconsin | Pulliam | 8 | 133 | 1964 |
| Wisconsin | South Oak Creek | 7 | 298 | 1965 |
| Wisconsin | South Oak Creek | 8 | 312 | 1967 |
| Wisconsin | Valley | 1 | 70.0 | 1968 |

| State Name | Plant Name | Unit ID | Capacity (MW) | On Line Year |
|---|---|---|---|---|
| Wisconsin | Valley | 2 | 70.0 | 1968 |
| Wisconsin | Valley | 3 | 70.0 | 1969 |
| Wisconsin | Valley | 4 | 70.0 | 1969 |
| Wisconsin | Weston | 3 | 338 | 1981 |
| Wyoming | Dave Johnston | BW43 | 220 | 1964 |
| Wyoming | Dave Johnston | BW44 | 330 | 1972 |
| Wyoming | Jim Bridger | BW71 | 530 | 1974 |
| Wyoming | Jim Bridger | BW72 | 530 | 1975 |
| Wyoming | Jim Bridger | BW73 | 530 | 1976 |
| Wyoming | Jim Bridger | BW74 | 530 | 1979 |
| Wyoming | Laramie River Station | 1 | 565 | 1980 |
| Wyoming | Laramie River Station | 2 | 570 | 1981 |
| Wyoming | Naughton | 1 | 160 | 1963 |
| Wyoming | Naughton | 2 | 210 | 1968 |
| Wyoming | Naughton | 3 | 330 | 1971 |
| Wyoming | Neil Simpson | 5 | 14.6 | 1969 |
| Wyoming | Wyodak | BW91 | 335 | 1978 |

# Appendix B

## Analysis of Visibility Degradation at Four Class I Areas

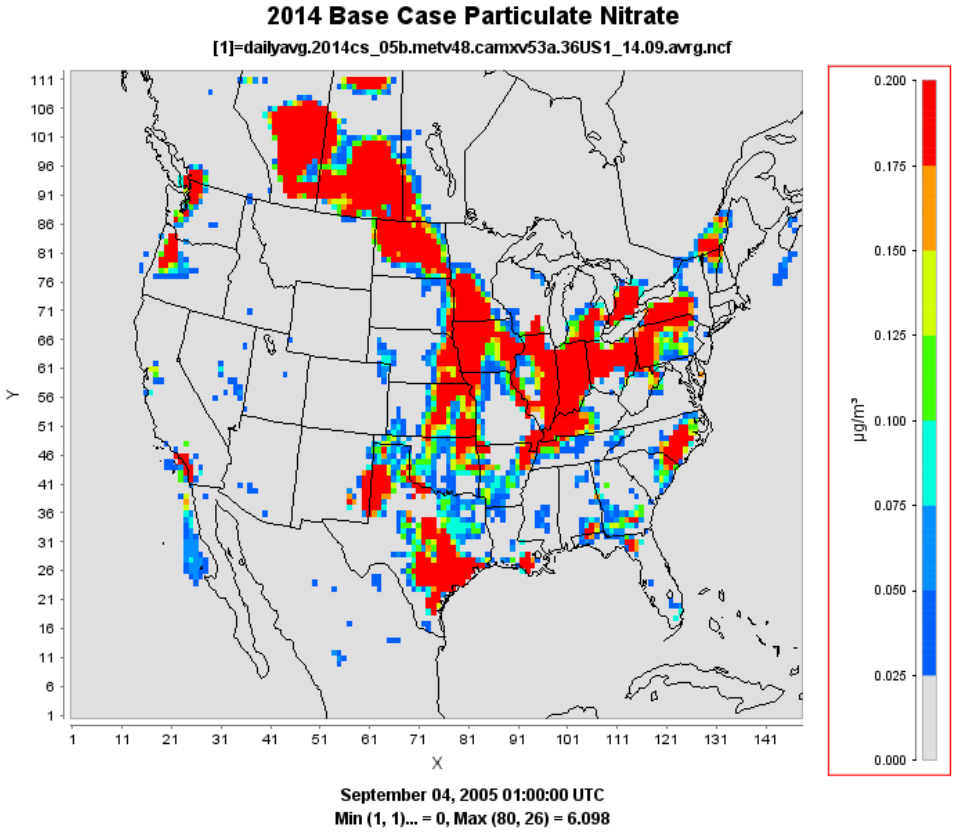
The default post-processing to calculate changes in visibility from the Transport Rule and nationwide BART (compared to the 2014 base case) showed apparent visibility degradation at four Class I areas, as shown in table B-1 below.

**Table B-1.** Visibility change for the 2014 "Transport Rule + BART-elsewhere" case compared to the 2014 base case (positive numbers represent degradation).

| Class I Area Name | IMPROVE ID | Representative IMPROVE Site | State | Visibility Change TR+BART-elsewhere 20% Best days | Visibility Change TR+BART-elsewhere 20% Worst days |
|---|---|---|---|---|---|
| Bryce Canyon NP | BRCA | BRCA1 | UT | **0.05** | -0.08 |
| Mazatzal Wilderness | MAZA | IKBA1 | AZ | -0.02 | **0.23** |
| Pine Mountain Wilderness | PIMO | IKBA1 | AZ | -0.02 | **0.23** |
| Saguaro NM | SAGU | SAGU1 | AZ | -0.24 | **0.26** |

All four of the Class I areas are located in the western portion of the 36km modeling domain (outside of the 12km modeling domain). In the CAMx output for the grid cells in the vicinity of these four Class I areas, we observed that in most cases, modeled concentrations of nitrate were very low on the 20 percent worst days (and 20 percent best days at Bryce Canyon) in both the "Transport Rule + BART-elsewhere" case and the "Nationwide BART" case. The modeled nitrate concentrations in these cases ranged from 0.001 to 0.004 $\mu g/m^3$, averaged across the 20 percent worst or best days in 2005. As an example, Figure B-1 shows the daily average nitrate concentration for September 4 (the figure shows the modeled concentration for September 4$^{th}$ in 2014), which is one of the measured 20% worst days at Saguaro National Monument. It can be seen that the modeled nitrate concentration in much of Arizona and large parts of the West are very small (the gray color is concentrations of < 0.0001 ug/m3).

**Figure B-1.** Modeled daily average particulate nitrate concentration in the 2014 base case scenario.




Notably, the modeled concentrations were generally a small fraction of monitored ambient nitrate concentrations at the IMPROVE sites for the four Class I areas. In the cases where degradation was calculated, a very small increase in modeled nitrate was observed on several of the worst or best modeled days. This led to a relatively large modeled percent increase in nitrate. Table B-2 shows the modeled daily average nitrate concentration on a single best or worst day at each of the four Class 1 areas. Among the 20% best or worst days at each of these Class I areas, these particular days had the largest percentage increase in nitrate. At each class I area, there were between 22 and 25 days that went into the best or worst days calculations.

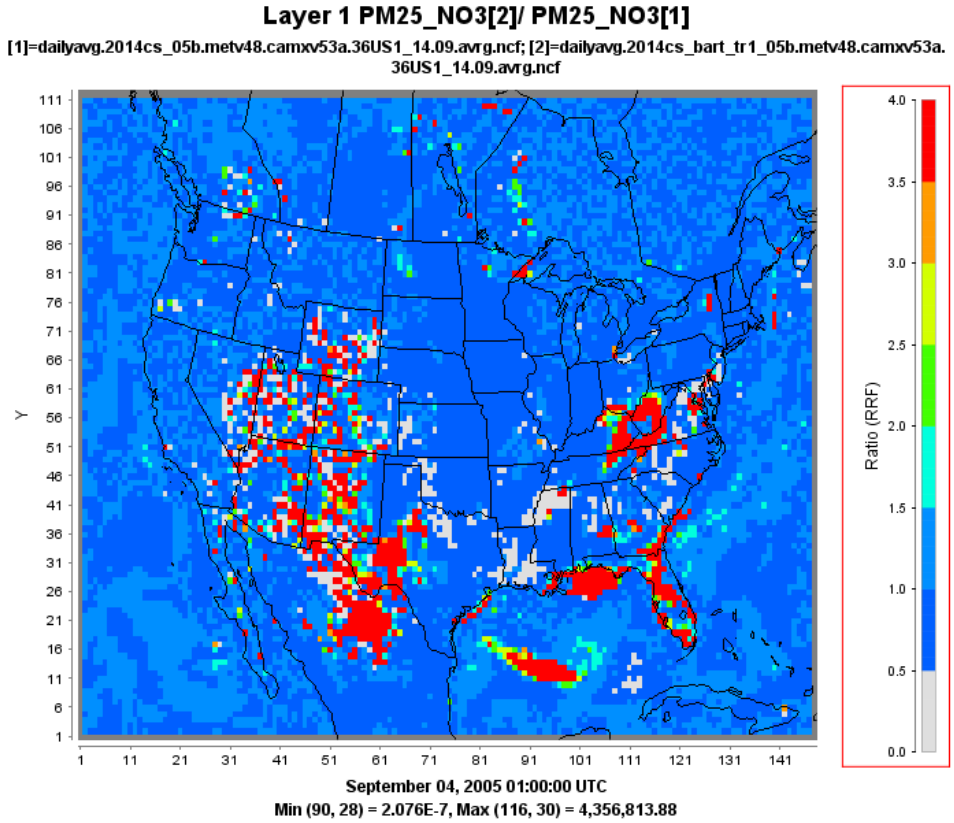
**Table B-2.** Modeled nitrate concentrations on the single best or worst day with the largest modeled nitrate increase between the 2014 base case and the 2014 Transport Rule scenario.

| Class I Area | State | Date | Best or Worst Day? | Modeled Nitrate Concentration 2014 Base Case (ug/m3) | Modeled Nitrate Concentration 2014 Transport Rule + BART-Elsewhere (ug/m3) | % Nitrate Increase |
|---|---|---|---|---|---|---|
| Mazatzal Wilderness | AZ | 9/10/2005 | Worst | 0.0003 | 0.0196 | 6533% |
| Pine Mountain Wilderness | AZ | 9/10/2005 | Worst | 0.0003 | 0.0196 | 6533% |
| Bryce Canyon NP | UT | 12/09/2005 | Best | 0.0047 | 0.015 | 319% |
| Saguaro NM | AZ | 9/04/2005 | Worst | 0.0096 | 0.0497 | 518% |

The large percentage increase in nitrate on a single day at Matzatzal and Pine Mountain has a large influence on the average nitrate RRF that is used in the visibility calculation. The average nitrate concentration (averaged over 23 days) on the worst days at Pine Mountain and Mazatzal increased from 0.001 $\mu g/m^3$ in the 2014 base case to 0.002 $\mu g/m^3$ in the "Transport Rule + BART-elsewhere" case. This is a very small increase that would not lead to noticeable changes in visibility; however it is a large percentage increase (100%). Since the modeled visibility test is based on relative changes in PM species, the very small increase in nitrate has a large impact on the final results.

Further examination of the days when these nitrate increases occur reveals a somewhat random pattern of very small increases and decreases that appear unrelated to EGU emissions changes. Figure B-2 shows the relative change in nitrate on September 4$^{th}$ between the 2014 base case and 2014 Transport Rule +BART-elsewhere case.

**Figure B-2.** Nitrate relative response factor on September 4th between the 2014 base case and the 2014 Transport Rule scenario (values > 1 are increases in nitrate in the control scenario).




While IPM predicts modestly higher $NO_X$ emissions in some nearby states under the "Transport Rule + BART-elsewhere" scenario, the checkerboard pattern of nitrate increases and decreases in the desert Southwest (among other areas) show no logical connection to these modestly higher emissions. This nitrate modeling issue appears similar to a previously noted nitrate chemistry stability issue when modeled concentrations are very small and relative humidity is very low.[33] The instability is related to the ISORROPIA nitrate partitioning mechanism that is used in CAMx to solve the partitioning of nitrate between the gas and particle phase. The same partitioning mechanism is used in both the CAMx and CMAQ models. An updated version of ISORROPIA (ISOROPPIA II) has been developed and reportedly has solved most of the instability issues encountered with the current version.[34]

Thus, we conclude that these positive and negative differences between very low nitrate

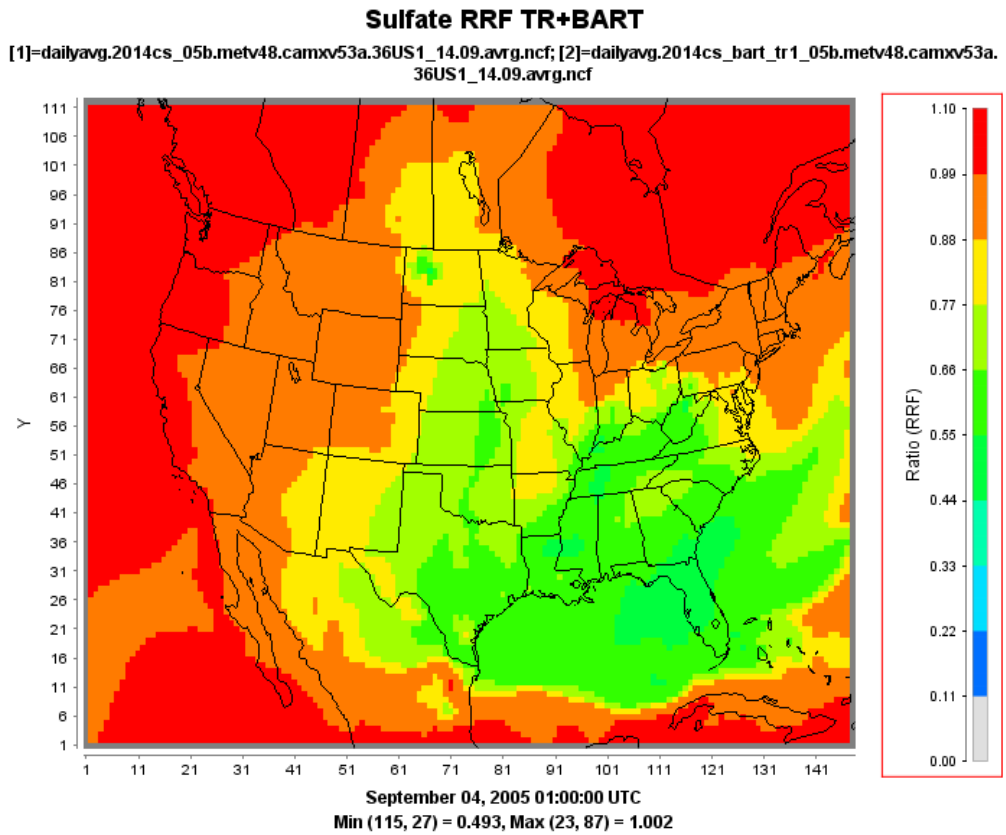
[33] Tong 2005, Numerical instability in the Community Multiscale Air Quality Model and its impacts on aerosol and ozone simulations, available at: http://www.princeton.edu/~mauzeral/papers/CMAQ_instability%20submission.pdf. And Bhave 2004, CMAQ Aerosol Module Development: Recent Enhancements and Future Plans, available at: http://www.cmascenter.org/conference/2004/abstracts/Model%20Development/bhave_abstract.pdf

[34] Fountoukis 2007, ISORROPIA II: a computationally efficient thermodynamic equilibrium model for $K^+$ –$Ca^{2+}$ –$Mg^{2+}$ –$NH_4^+$ –$Na^+$ –$SO_4^{2-}$ –$NO_3^-$ –$Cl^-$ –H2O aerosols, available at: http://www.atmos-chem-phys.org/7/4639/2007/acp-7-4639-2007.pdf

concentrations are a modeling artifact attributable to the ISORROPIA nitrate mechanism in CAMx for the conditions that apply in this geographic area on these days, and are not reasonable predictors of the true relative effects on visibility of the emission control scenarios.

As a comparison, we also examined the sulfate relative concentration on September 4th. Figure B-3 shows the relative change in sulfate on September 4th between the 2014 base case and 2014 Transport Rule +BART-elsewhere case. Note the smooth spatial pattern of sulfate relative changes.

**Figure B-3.** Sulfate relative response factor on September 4th between the 2014 base case and the 2014 Transport Rule scenario (values < 1 are decreases in sulfate in the control scenario).




To further analyze the cause of the visibility degradation, we performed an analysis to illustrate how sensitive the predictions of degradation are to highly variable results on particular days. For each of these four Class I areas, we removed the one day (the day at each site listed in table B-2) of the 20 percent worst or best days with the largest increase in modeled nitrate concentration. When the single day is removed, the apparent visibility degradations no longer occur. Table B-3 shows the default results with all days and the results when the single day is removed from the analysis.

**Table B-3.** Visibility results with all days and with one day removed from the calculations.

| Class I area | IMPROVE site | Visibility change default | Visibility change with one day removed | Number of modeled days in the best or worst days calculation |
|---|---|---|---|---|
| Bryce Canyon NP | BRCA | 0.05 (best) | -0.01 | 22 |
| Mazatzal Wilderness | MAZA | 0.23 (worst) | -0.01 | 23 |
| Pine Mountain Wilderness | PIMO | 0.23 (worst) | -0.01 | 23 |
| Saguaro NM | SAGU | 0.26 (worst) | -0.06 | 25 |

The large percentage increase in nitrate can also be accounted for in the post-processing of the model results by setting a minimum concentration RRF threshold when calculating RRFs for all PM species. If the average species concentration across all best or worst days at each site is below the minimum threshold, then the RRF for that particular species would be set to 1.0. To test this, the regional haze post-processing software (MATS) was run again with a minimum average concentration threshold of 0.01 ug/m3. Table B-4 shows the results of this analysis.

**Table B-4.** Change in visibility between the 2014 base case and the 2014 Transport Rule scenario when a minimum RRF threshold (0.01 ug/m3) is set in the post-processing software.

| Class I area | IMPROVE site | Visibility Change TR1+BART best days | Visiblity Change TR1+BART worst days |
|---|---|---|---|
| Bryce Canyon NP | BRCA | -0.01 | -0.08 |
| Mazatzal Wilderness | MAZA | -0.02 | -0.01 |
| Pine Mountain Wilderness | PIMO | -0.02 | -0.01 |
| Saguaro NM | SAGU | -0.24 | -0.06 |

As can be seen from Table B-4, if a minimum RRF threshold of 0.01 ug/m3 is used, the degradation no longer occurs at any Class I area. Based on this information, the EPA is considering whether to implement a minimum threshold concentration as part of the default Regional Haze calculations. The minimum threshold would be built into the MATS software used to post-process photochemical outputs. These possible revisions are aimed at avoiding potentially misleading results in situations such as the one observed near these particular Western Class I areas.

Based on these additional analyses of the visibility modeling results, we are confident that no degradation in the four western Class I areas will result from implementation of the Transport Rule trading program in the Eastern U.S.

# Appendix C

## Sensitivity Analysis Accounting for Proposed Increases in Certain Transport Rule State Budgets

The Better than BART modeling analysis for this proposed rule was completed using the emissions totals from the final Transport Rule, and also assuming that the July 11, 2011 proposal regarding ozone-season NOx emissions in five states will be finalized.[35] Recently, EPA proposed[36] to make adjustments to the EGU SO2 and NOx budgets in several states. In all cases, the budgets are proposed to be increased. Table C-1 summarizes the proposed budget increases.

**Table C-1.** Proposed increases in Transport Rule 2014 SO2 and NOx Budgets

| State | 2014 $SO_2$ Budget Increase (tons) | 2014 NOx Budget Increase (tons) |
|---|---|---|
| Louisiana | N/A | 4,231 |
| Mississippi | N/A | 2,136 |
| Michigan | N/A | 5,228 |
| Nebraska | N/A | 3,559 |
| New Jersey | N/A | 112 |
| New York | 3,527 | 3,485 |
| Texas | 70,067 | 1,375 |
| Wisconsin | 7,757 | 2,473 |
| **Total Increase** | **81,351** | **22,599** |

The proposed $SO_2$ and NOx budget increases are relatively modest compared to the total modeled reductions from the Transport Rule. The modeled $SO_2$ reductions from the Transport Rule are ~3.8 million tons per year and NOx reductions are ~125,000 tons per year. In addition, considering the proposed budget increases, the "Transport Rule +BART-elsewhere" control scenario is still projected to result in about 26,000 tons more NOx emission reductions than "nationwide BART" and about 821,000 tons more $SO_2$ emission reductions than "nationwide BART". The only increase in emissions that is large enough to potentially affect the Better than BART analysis is the $SO_2$ budget increase in Texas. This is due to the relatively large increase in Texas $SO_2$ compared to other states, and the fact that $SO_2$ emissions account for the majority of the $PM_{2.5}$ and visibility impacts from the Transport Rule. Therefore, we completed a more detailed sensitivity analysis of the potential impact from the Texas $SO_2$ budget increase.

35 The air quality modeling conducted for this analysis included in the CSAPR scenario the states addressed in the July 11 proposal. These states are Iowa, Kansas, Michigan, Nebraska, Minnesota, and Oklahoma.

36 Revisions to the Federal Implementation Plans to Reduce Interstate Transport of Fine Particulate Matter and Ozone, 76 FR 63860 (October 14, 2011)

Table C-2 shows the Texas $SO_2$ emissions as modeled in the Better than BART analysis and the emissions that would occur if the state budget is increased as proposed.

**Table C-2. Texas 2014 SO2 emissions and decreases compared to the 2014 modeled base case**

| 2014 Base Case $SO_2$ Emissions | 2014 TR+ BART-elsewhere $SO_2$ Emissions (estimate from IPM used in air quality modeling) | 2014 Proposed Budget Increase | $SO_2$ Emissions Decrease from TR (as modeled) | $SO_2$ Emissions Decrease from TR with Increased Budget |
|---|---|---|---|---|
| 453,332 | 266,627 | 70,067 | -186,705 | -116,638 |

Table C-2 shows that the modeled $SO_2$ reduction in Texas is ~186,000 tons per year. After accounting for the proposed increase in the $SO_2$ budget for Texas, the $SO_2$ emissions reduction is still ~116,000 tons per year. This would reduce the total $SO_2$ reduction from the Transport Rule from ~3.8 million tons per year to ~3.7 million tons per year.

It can be seen from Table C-2 that even with the increase in the $SO_2$ budget for Texas, there is still a large $SO_2$ **reduction** in Texas, compared to the 2014 base case and the impact on the total net $SO_2$ reduction from the Transport Rule is minimal (< 2% decrease in $SO_2$ reductions).

Given this information, we would still expect major visibility improvements at Class I areas in and around Texas from the Transport Rule. However, in order to better inform the process, we performed a very conservative sensitivity analysis to provide a limiting upper estimate of the worst case impact of increases in Texas $SO_2$ allowances.

Sensitivity Analysis of Better than BART with Increased Texas $SO_2$ Allowances

We identified the most likely "affected" Class I areas for Texas and then assumed that these areas would get zero benefit from the Transport Rule. Table C-3 shows the 9 Class I areas in and near Texas that were identified as the affected areas.[37] We identified these areas by looking at the regional haze analysis conducted by the CENRAP regional planning organization in support of the development of regional haze SIPs in Texas and surrounding states.

37 Affected Class I areas were identified by examining consultation letters from states surrounding Texas which were included in the Texas regional haze SIP submissions. The letters are included in Appendix 4-3 available here: http://www.tceq.texas.gov/airquality/sip/bart/haze_appendices.html. We included 6 areas which had a > 2 $Mm^{-1}$ impact from Texas. These areas had much higher visibility impacts from Texas compared to other analyzed Class I areas. We also included the 3 Class I areas that are in Texas or are represented by an IMPROVE monitor that is located in Texas.

**Table C-3.** Class I areas most affected by Texas emissions and the modeled visibility improvement from the Transport Rule + BART-elsewhere case.

| **Class I Area Name** | **State** | TR+BART-elsewhere 20% Best days | TR+BART-elsewhere 20% Worst days |
|---|---|---|---|
| Big Bend NP | TX | -0.2 | -1.1 |
| Caney Creek Wilderness | AR | -0.4 | -3.2 |
| Carlsbad Caverns NP | TX | -0.1 | -0.9 |
| Guadalupe Mountains NP | TX | -0.1 | -0.9 |
| Hercules-Glades Wilderness | MO | -0.6 | -2.5 |
| Salt Creek | NM | -0.1 | -0.7 |
| Upper Buffalo Wilderness | AR | -0.5 | -2.5 |
| White Mountain Wilderness | NM | -0.1 | -0.6 |
| Wichita Mountains | OK | -0.2 | -1.6 |

For this analysis, we assumed that the visibility benefits shown in Table C-3 would become zero as a result of the allowance adjustment for SO2 in Texas. This is a very conservative assumption because there would still be 116,000 tons per year of $SO_2$ reductions in Texas and this also assumes that there would be no visibility benefits in these 9 Class I areas from the ~3.6 million tons of $SO_2$ reductions from the other Transport Rule states. This is not a realistic assumption, but one that we use here in order to be conservative.

Sensitivity Analysis Results

We recalculated the average visibility changes at the 60 Eastern and 140 nationwide Class I areas in the Better than BART analysis, assuming that the visibility change at the 9 Class I areas in Table C-3 would be zero. The first prong of the Better than BART test would still be passed because there will be no degradation in visibility at any Class I areas on either the 20% best or 20% worst days. Table C-4 below shows the average visibility results and the re-calculated average visibility results for the Texas sensitivity case.

**Table C-4.** Average visibility improvement on the 20% best and 20% worst days in the Better than BART analysis and the Texas sensitivity analysis.

| | "Transport Rule + BART-elsewhere" | "Transport Rule + BART-elsewhere" Texas Sensitivity Case | "Nationwide BART" |
|---|---|---|---|
| 60 Class I Areas in the Eastern Transport Rule Modeling Domain | | | |
| 20 percent Worst Days | 1.6 | 1.3 | 1.0 |
| 20 percent Best Days | 0.3 | 0.3 | 0.2 |
| 140 Class I Areas in the Western and Eastern Transport Rule Modeling Domains | | | |
| 20 percent Worst Days | 0.7 | 0.6 | 0.5 |
| 20 percent Best Days | 0.1 | 0.1 | 0.1 |

Table C-4 shows that the even with the very conservative assumptions in this analysis, the Transport Rule+ BART-elsewhere case is still, on average, better than (or equal to) nationwide BART on both the 20% best and 20% worst days at the 60 Eastern Class I areas and at the 140 nationwide Class I areas.

# EXHIBIT 19

# Air Quality Modeling Analysis of the Impacts of Emissions from Seven Texas-Located Point Source Facilities on Visibility at Four Class 1 Areas in Texas, Arkansas and Oklahoma

Prepared For:

Stephanie Kodish

National Parks Conservation Association

Midwest Regional Office

8 S. Michigan, Suite 2900

Chicago, IL 60603

Prepared by:

Tammy M Thompson, PhD

Postdoctoral Associate

MIT Joint Program for the Science and Policy of Global Change

77 Massachusetts Ave.  Bldg E19-411

Cambridge, MA 02139

March 21, 2012

## Executive Summary

Two photochemical modeling simulations were performed using meteorological data from a year-long January 1, 2005 to December 31, 2005 episode, with a projected 2014 anthropogenic emissions inventory developed by the United States Environmental Protection Agency (U.S.EPA) in support of the Cross State Air Pollution Rule (CSAPR). The objective of the modeling study was to estimate the impacts of emissions associated with four coal-fired power plants, and three Best Available Retrofit Technology (BART) eligible point source facilities, all located in Texas, on visibility at four Class 1 areas in Texas, Arkansas and Oklahoma. The Class 1 Areas of interest are: Big Bend National Park and Guadalupe Mountains National Park in Texas, Caney Creek Wilderness in Arkansas and the Wichita Mountains in Oklahoma.

The first photochemical modeling simulation is a base case representing the 2014 emissions inventory, including CSAPR proposed controls, unchanged as developed and finalized in July 2011 by the U.S.EPA. The second simulation is the same at the base case except that emissions associated with seven point source facilities in Northeast Texas have been removed from the simulation. Impacts on visibility at the four Class 1 areas of interest were estimated by calculating the change in the modeled visibility between the scenario case and the base case, for each day of the episode, at each site.

Visibility is impacted when light strikes gas or particles in the atmosphere and is scattered or absorbed. Therefore, decreases in visibility are estimated using modeled concentrations of gaseous or particulate species in the atmosphere. The Haze Index, a measure of visibility (in units of deciviews), was calculated from modeled concentrations of specific particles and gas, for each day of the modeling year. The top 20 best and 20 worst visibility days were identified for each simulation at each of the four Class 1 areas. The average of the top 20 best visibility days (days with the lowest haze index) was calculated and the difference between the scenario case and the base case represents the estimated impact of the emissions from the seven point sources in Texas on visibility on good days at that site. The same calculation was done to evaluate the impact of those seven sources on bad visibility days (days with the highest haze index) at each site.

The average modeled impact of those seven sources on good visibility days ranged from 0.01 deciviews (at Big Bend, Guadalupe Mountains, and Wichita Mountains) to 0.45 deciviews at Caney Creek. The average modeled impact of those seven sources on bad visibility days ranged from 0.12 deciviews at Wichita Mountains to 0.28 deciviews at Guadalupe Mountains.

## Table of Contents

Page

I. Introduction ..... 5

II. Air Quality Modeling Episodes ..... 5

a. Cross State Air Pollution Rule 2014 Remedy Case: Base Case ..... 7

b. Cross State Air Pollution Rule 2014 Remedy Case with Emissions from Seven Texas Point Sources Removed: Scenario Case ..... 7

III. Methods: Calculating Visibility in four Class 1 Areas in Texas, Arkansas and Oklahoma 8

IV. Results ..... 11

V. Summary ..... 19

VI. References ..... 20

## List of Figures

Figure 1. CSAPR 36 km and 12 km Modeling Domains (EPA 2011e). ..... 7

Figure 2. Location of four selected Texas-located coal-fired power plants (red triangles), three additional BART eligible emissions sources (blue triangles), and four Class 1 areas (green squares). ..... 9

Figure 3 (a-d). Difference in modeled particulate sulfate concentrations (Scenario case – base case, $\mu g/m^3$) due to the removal of emissions associated with the seven Texas point sources, on October 15th, August 10th, October 14th, and May 29th. ..... 19

## List of Tables

Table 1. Emissions from seven Facilities of Interest, According to the U.S. EPA's 2014 "Remedy Case" Cross State Air Pollution Rule Emissions Inventory ..... 8

Table 2. Coordinates, Rayleigh Coefficient (Mm-1), and unit less Relative Humidity factors for each of the four Class 1 Area Monitor Sites. ..... 11

Table 3. Average haze index for the 20 best and 20 worst visibility days for the base case, the scenario case, the difference between the averages and the number of single day differences greater than 0.5 dv for each of the four Class 1 Area Monitor Sites. ..... 12

Table 4. Date, base case haze index, scenario case haze index and difference for the 20 best and 20 worst visibility days, based on the base case haze index, for Big Bend National Park. ..... 13

Table 5. Date, base case haze index, scenario case haze index and difference for the 20 best and 20 worst visibility days, based on the base case haze index, for Caney Creek Wilderness Area. ..... 13

Table 6. Date, base case haze index, scenario case haze index and difference for the 20 best and 20 worst visibility days, based on the base case haze index, for Guadalupe Mountains National Park. ..... 14

Table 7. Date, base case haze index, scenario case haze index and difference for the 20 best and 20 worst visibility days, based on the base case haze index, for Wichita Mountains. ..... 14

Table 8. Date, base case haze index, scenario case haze index and difference for the 20 days with the largest and the 20 days with the smallest difference in visibility for Big Bend National Park. ..... 16

Table 9. Date, base case haze index, scenario case haze index and difference for the 20 days with the largest and the 20 days with the smallest difference in visibility for Caney Creek Wilderness Area. ..... 16

Table 10. Date, base case haze index, scenario case haze index and difference for the 20 days with the largest and the 20 days with the smallest difference in visibility for Guadalupe Mountains National Park. ..... 17

Table 11. Date, base case haze index, scenario case haze index and difference for the 20 days with the largest and the 20 days with the smallest difference in visibility for Wichita Mountains. ..... 17

Table 12. The light extinction coefficients (Mm-1) of each particulate species plus gaseous $NO_2$, for the dates characterized by the largest increase in visibility (decrease in haze index) due to the removal of emissions associated with seven Texas point sources, at each of the four Class 1 areas. ..... 18

## I. Introduction

This report documents the development and results of two photochemical modeling runs designed to evaluate the modeled impacts of emissions associated with the operation of four existing coal-fired power plants plus three additional Best Available Retrofit Technology (BART) eligible point source facilities, all located in the state of Texas, on modeled visibility at four Class 1 areas in Texas, Oklahoma and Arkansas. This study uses a publically available year-long modeling episode developed by the United States Environmental Protection Agency (U.S. EPA) in support of the Cross State Air Pollution Rule (CSAPR) as finalized in July 2011. The emissions inventories for this episode represent emissions projected to 2014 and were downloaded from the EPA website in August 2011 (EPA 2011a). Meteorological inputs for the CSAPR modeling episode, representing conditions as they occurred in 2005, were sent via external hard drive to Tammy Thompson from the EPA in August 2011. Visibility impacts were investigated at the following four Class 1 area monitors of interest: Big Bend National Park, Guadalupe Mountains National Park, Caney Creek Wilderness, and Wichita Mountains.

## II. Air Quality Modeling Episodes

The input emissions inventories for two photochemical modeling simulations are developed for the analyses presented in this report using the Sparse Matrix Operator Kernal Emissions (SMOKE) preprocessing system (CMAS, 2009). SMOKE processes emissions inventories to create gridded and speciated hourly emissions files that are ready for input to air quality models. SMOKE is also used to apply control factors to individual facilities, or groups of facilities based on facility type or location.

Once the emissions inventories are processed using SMOKE, the simulations are then run using the Comprehensive Air Quality Model with extensions (CAMx) (www.camx.com). CAMx is a 3-Dimensional, Eularian photochemical model that simulates the emission, movement, chemistry and removal of chemical species in the atmosphere (ENVIRON, 2010). CAMx is approved by the EPA for regulatory air quality modeling purposes and was the model used in support of the CSAPR.

CAMx version 5.3 is used for this study with the Carbon Bond 5 (cb05) chemical mechanism. The modeling domain, shown in **Figure 1**, is the 12EUS1 domain and covers the Eastern half of the U.S. and all grid cells within the domain have 12 km by 12 km resolution. Individual grid cells are not shown in Figure 1; instead, the outline of the domain is shown. Within the 12 km domain, there are 240x279 grid cells that are 12 km on each side.

The meteorological inputs (including temperature, wind speed and direction, pressure, water vapor, cloud/rain, vertical diffusivity, and albedo) were developed by the U.S.EPA using the Pennsylvania State University/ National Center for Atmospheric Research Mesoscale Model (MM5) (Grell *et al*., 1994). The meteorological inputs remain the same for each of the two

simulations described below and represent conditions as they occurred on the episode dates in 2005.

The baseline episode for each of the two simulations is the year-long (January 1st through December 31st) 2014 "Remedy" case as developed by the U.S. EPA in support of the CSAPR and finalized in July 2011. The CSAPR was designed to aid states in meeting attainment of the National Ambient Air Quality Standards (NAAQS) for six species of air pollution called criteria pollutants (EPA 2011b). Sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) emissions caps were set in 28 states and the level of these caps were designed to prevent upwind states from impacting the attainment status of downwind locations in addition to reducing intrastate pollution (EPA 2011c). The 2014 remedy case emissions inventory was generated by the EPA to reflect emissions projected to 2014 and includes these caps (EPA 2011d). The details of the emissions inventory developed for the 2014 remedy case episode can be found in the document titled: "Technical Support Document (TSD) for the final Transport Rule Docket ID No. EPA-HQ-OAR-2009-0491" (EPA 2011d).

Boundary and initial conditions for the simulations conducted for this analysis were generated using output from the CSAPR 2014 remedy case, run unchanged, at the 36 km resolution domain (the CONUS domain – also shown in Figure 1). The Goddard Earth Observing System 3-D chemical transport model (GEOS-CHEM) was used to generate boundary and initial conditions for the modeling runs conducted at 36 km resolution (EPA, 2011e). Because the 12 km resolution domain covers all emissions sources and visibility monitors that are being evaluated in this study, and therefore all sources located outside of the 12 km domain do not change between the base case and the scenario case, the boundary conditions remain the same for each of the two runs described below. The year-long modeling episode has been split into four separate simulations in order to reduce model run time: January through March, April through June, July through September, and October through December. All of the inputs and procedures described above use the same methods used by the EPA in the modeling done in support of the CSAPR.

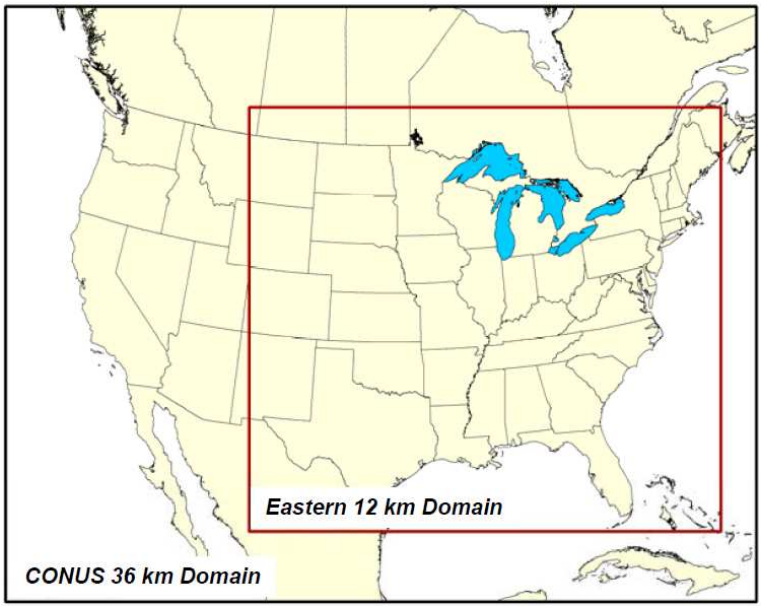


Figure 1. CSAPR 36 km and 12 km Modeling Domains (EPA 2011e).

The following two sections describe the methods used for the development of the two air quality simulations performed for this analysis.

**a. Cross State Air Pollution Rule 2014 Remedy Case: Base Case**

The 2014 remedy case emissions inventory is run with inputs as described above. The emissions inventories and all other procedures and inputs are run in the same way as designed by the U.S. EPA in support of the CSAPR. This model run will serve at the base case.

**b. Cross State Air Pollution Rule 2014 Remedy Case with Emissions from Seven Texas Point Sources Removed: Scenario Case**

In addition to the 2014 CSAPR remedy case (base case), a scenario case is run, and the only change from the base case will be the removal of emissions associated with seven point source facilities in the State of Texas. The seven facilities were identified by the National Parks Conservation Association as facilities of interest for this study.

The first four facilities are coal-fired power plants located in Texas. All emissions from these four facilities are removed from the base case (With a single exception: There is a third unit at the Welsh power plant and the emissions associated with that unit will not be removed as requested by the NPCA). These four coal-fired power plants are: Welsh (Units 1 and 2), Monticello (Units 1-3), Big Brown (Units 1 and 2), and Martin Lake (Units 1-3). The emissions associated with three additional BART eligible point source facilities are also removed from the base case. The three additional BART-eligible point source facilities are:

Texarkana International Paper, Eastman Chemical Company and TXI Operations Cement. **Figure 2** below shows the locations of these seven facilities.

**Table 1** lists the seven Texas-located emissions point sources, and annual average emissions according to the CSAPR remedy case 2014 emissions inventory. Table 1 does not include Welsh Unit 3. All of the emissions reported in Table 1 are removed from modeling. This model run will be referred to as the Scenario Case. By comparing the results of this modeling simulation to the Base Case (the unchanged 2014 remedy case), the impacts that emissions from these seven Texas-located point source facilities have on visibility in four class 1 areas in Texas, Arkansas and Oklahoma will be estimated.

Table 1. Emissions from seven Facilities of Interest, According to the U.S. EPA's 2014 "Remedy Case" Cross State Air Pollution Rule Emissions Inventory

| | Annual Average Emissions (Tons) | | | | | | |
|---|---|---|---|---|---|---|---|
| Facility Name | CO | $NO_X$ | VOC | $SO_2$ | $NH_3$ | $PM_{10}$ | $PM_{2.5}$ |
| Welsh Power Plant (2 of 3 Units) | 1018.48 | 6391.05 | 122.22 | 11750.05 | 61.11 | 371.86 | 371.06 |
| Big Brown | 1402.31 | 6940.89 | 168.28 | 28353.06 | 84.14 | 496.15 | 495.52 |
| Martin Lake | 2866.13 | 17407.00 | 343.94 | 5968.52 | 171.97 | 2803.94 | 1832.88 |
| Monticello | 2612.17 | 12404.48 | 341.36 | 56195.18 | 164.96 | 2491.18 | 2050.91 |
| Eastman Chemical Co | 1865.73 | 2431.42 | 2854.71 | 20.41 | 4.69 | 215.74 | 200.24 |
| Texarkana Paper Mill | 868.36 | 1618.73 | 2167.55 | 373.71 | 132.11 | 596.19 | 329.12 |
| TXI Operations LP | 190.41 | 613.19 | 252.46 | 3549.84 | 0* | 169.20 | 93.67 |
| Annual total | 10823.59 | 47806.76 | 6250.51 | 106210.76 | 618.97 | 7144.26 | 5373.40 |
| Average Daily total | 29.65 | 130.98 | 17.12 | 290.99 | 1.70 | 19.57 | 14.72 |

* Zero NH3 Emissions were found for TXI Operations in the Emissions Inventory

## III. Methods: Calculating Visibility in four Class 1 Areas in Texas, Arkansas and Oklahoma

This study reports the modeled impacts of emissions associated with four existing coal-fired power plants plus three additional BART eligible point source facilities, all located in the state of Texas, on modeled visibility at four Class 1 areas in Texas, Oklahoma and Arkansas. The Class 1 areas that are evaluated are: Big Bend National Park and the Guadalupe Mountains in Texas, the Caney Creek Wilderness in Arkansas, and the Wichita Mountains in Oklahoma. The locations of these four areas are shown in Figure 2.

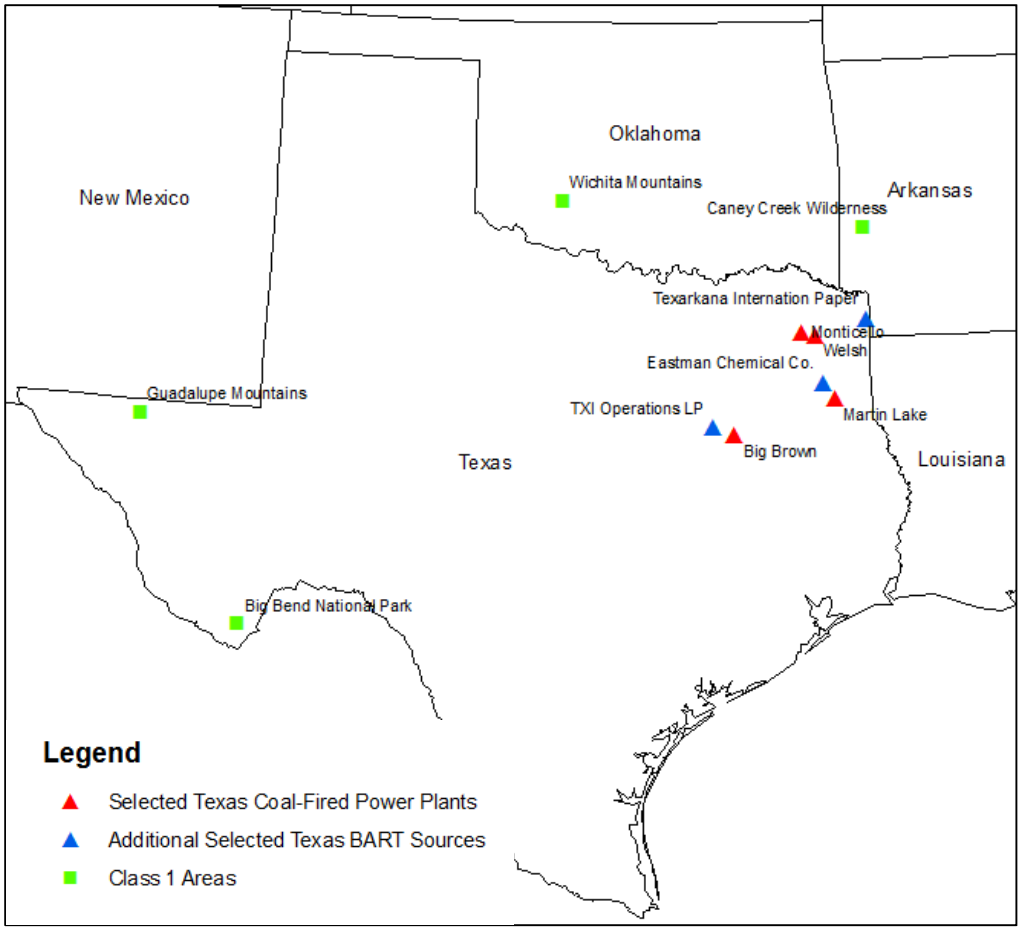



Figure 2. Location of four selected Texas-located coal-fired power plants (red triangles), three additional BART eligible emissions sources (blue triangles), and four Class 1 areas (green squares).

Visibility is reduced when light hits gases or particles in the air and is scattered or absorbed. The particulate component of scattering and absorption is calculated using modeled ambient concentrations of particulate matter (PM) species. These modeled concentrations of PM species will be applied to the latest Interagency Monitoring of Protected Visual Environments (IMPROVE) light-extinction algorithms in two steps (Pitchford *et al*. 2007) as recommended by the EPA guidance (EPA, 2007). The first step is represented by Equation 1 and involves calculating the individual light extinction coefficients for each species (in $Mm^{-1}$) and summing them together. The second step of the IMPROVE algorithm is represented in Equation 2 and involves calculating the haze index value (in deciviews) from the total light extinction value.

The modeled PM species that are included in the calculation of the light extinction coefficient (with their respective CAMx model species) are: particulate sulfate (PSO4), particulate nitrate (PNO3), elemental carbon (PEC), primary (POA) and secondary (SOA1-5) organic mass, fine soil (FCRS, FPRM), and coarse particulate mass (CCRS, CPRM). Daily (24 hour average) values for each species are calculated using the average modeled value within a 3x3 matrix of grid cells surrounding the 12 km grid cell containing the visibility monitor location, for each day

of the episode year following the procedures presented in the EPA guidance document (EPA 2007). These modeled daily concentration values are then applied to Equation 1 below. The units for each of the particulate species concentration values are $\mu g/m^3$.

The gaseous component of absorption is dominated by $NO_2$, and the gaseous component of scattering is represented by the site-specific Rayleigh scattering coefficient that is calculated based on the elevation and annual average temperature at each site (Pitchford *et al*. 2007). The Rayleigh scattering value for each site, according to the University of Colorado's Visibility Information Exchange Web System (VIEWS) website (VIEWS, 2012), is listed in **Table 2**. Also obtained from the VIEWS site and listed in Table 2 are the monthly relative humidity values specific to each of the four Class 1 sites (VIEWS, 2012).

$$b_{ext} = b_{Ray} + b_{Sulfate} + b_{Nitrate} + b_{EC} + b_{OMC} + b_{Soil} + b_{CM} + b_{NO2} + b_{NaCl} \qquad \text{(Equation 1)}$$

where

$b_{Ray}$ = Site Specific Rayleigh Scattering Value

$b_{Sulfate} = 2.2 \times f_S(RH) \times [\text{Small Sulfate}] + 4.8 \times f_L(RH) \times [\text{Large Sulfate}]$

$b_{Nitrate} = 2.4 \times f_S(RH) \times [\text{Small Nitrate}] + 5.1 \times f_L(RH) \times [\text{Large Nitrate}]$

$b_{EC} = 10 \times [\text{Elemental Carbon}]$

$b_{OMC} = 2.8 \times [\text{Small Organic Mass}] + 6.1 \times [\text{Large Organic Mass}]$

$b_{Soil} = 1 \times [\text{Fine Soil}]$

$b_{CM} = 0.6 \times [\text{Coarse Mass}]$

$b_{NO2} = 0.33 \times [\text{NOx (ppb)}]$

$b_{NaCl} = 1.7 \times f_{SS}(RH) \times [\text{Sea Salt}]$ (assumed to be zero for this study)

Particulate sulfate, particulate nitrate, and total organic mass are apportioned into small and large components using the following equations (presented using sulfate, but applied in the same way to nitrate and organic mass):

$$[\text{Large Sulfate}] = \frac{[\text{Total Sulfate}]}{20\ \mu g/m^3} \times [\text{Total Sulfate}] \qquad \text{for } [\text{Total Sulfate}] < 20\ \mu g/m^3$$

$$[\text{Large Sulfate}] = [\text{Total Sulfate}] \qquad \text{for } [\text{Total Sulfate}] \geq 20\ \mu g/m^3$$

$$[\text{Small Sulfate}] = [\text{Total Sulfate}] - [\text{Large Sulfate}]$$

The extinction due to sea salt is assumed to be zero due to the inland location of the four Class 1 sites. This is a good assumption based on measured data from each Class 1 area of interest downloaded from the VIEWS website (VIEWS 2012).

The extinction coefficient calculated using equation 1 for each day of both the base case and the scenario case will be applied to equation 2 to calculate the haze index (HI) value in deciviews (representing a measure of degradation in visibility) (Pitchford *et al*. 2007).

$$HI_{source} = 10 \times \ln \left[\frac{b_{ext}}{10}\right] \qquad \text{(Equation 2)}$$

Values for modeled haze index will be calculated for each day of the modeling year, for each of the two modeling scenarios (base case and scenario case) using Equations 1 and 2. The 20 days from the base case modeling episode with the largest haze index value will be identified, and the haze index values for both the base case and the scenario case yearly modeling episodes will be reported for each of those days. The average of those 20 days will also be calculated and reported for each model run. The difference in deciviews between the average values for the 20 largest haze index days of the scenario case and the base case will represent the modeled change in visibility on "bad" visibility days due to the removal of emissions from the seven facilities of interest. The procedure will be repeated with the 20 days with the lowest haze index value and the difference in deciviews between the averaged values of the two model runs will represent the change in visibility on "good" visibility days.

This procedure differs from procedures used for regulatory purposes in that it does not rely on measured speciated data and instead calculates visibility directly from modeled concentrations of particulate matter species plus $NO_2$.

Table 2. Location Coordinates, Rayleigh Coefficient (Mm-1), and unit-less Relative Humidity factors for each of the four Class 1 Area Monitor Sites.

| | Longitude | Latitude | Rayleigh | | Jan | Feb | Mar | Apr | May | June | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Big Bend National Park | -103.178 | 29.303 | 10 | $f_L(RH)$ | 1.67 | 1.57 | 1.42 | 1.37 | 1.45 | 1.47 | 1.56 | 1.72 | 1.80 | 1.61 | 1.60 | 1.65 |
| | | | | $f_S(RH)$ | 2.03 | 1.86 | 1.63 | 1.54 | 1.64 | 1.65 | 1.81 | 2.04 | 2.16 | 1.89 | 1.87 | 1.96 |
| Caney Creek | -94.143 | 34.454 | 11 | $f_L(RH)$ | 2.77 | 2.53 | 2.37 | 2.43 | 2.68 | 2.71 | 2.59 | 2.60 | 2.71 | 2.69 | 2.67 | 2.79 |
| | | | | $f_S(RH)$ | 3.85 | 3.44 | 3.14 | 3.24 | 3.66 | 3.71 | 3.49 | 3.51 | 3.73 | 3.72 | 3.68 | 3.88 |
| Guadalupe Mountains | -104.809 | 31.833 | 9 | $f_L(RH)$ | 2.14 | 1.82 | 1.49 | 1.38 | 1.48 | 1.47 | 1.78 | 1.98 | 2.10 | 1.60 | 1.78 | 2.08 |
| | | | | $f_S(RH)$ | 2.85 | 2.28 | 1.74 | 1.57 | 1.73 | 1.69 | 2.16 | 2.48 | 2.74 | 1.90 | 2.20 | 2.71 |
| Wichita Mountains | -98.713 | 34.732 | 11 | $f_L(RH)$ | 2.39 | 2.25 | 2.10 | 2.11 | 2.39 | 2.24 | 2.02 | 2.13 | 2.35 | 2.22 | 2.28 | 2.41 |
| | | | | $f_S(RH)$ | 3.17 | 2.94 | 2.69 | 2.68 | 3.15 | 2.86 | 2.49 | 2.70 | 3.07 | 2.87 | 2.97 | 3.20 |

## IV. Results

This section summarizes the results of the modeling simulations designed to evaluate the potential impacts of emissions associated with four Texas Coal-Fired power plants, and three additional BART eligible point sources on modeled visibility at four Class 1 areas in Texas, Oklahoma and Arkansas.

**Table 3** below presents the average of the 20 best and 20 worst visibility days, based on the haze index calculation described above, for the base case and the scenario case, as well as the difference between the average haze index, for each of the four Class 1 areas of interest. Additionally, the number of days for each Class 1 area where the difference between the base case haze index, and the scenario case haze index is greater than 0.5 dv is calculated and reported.

For the case of Caney Creek, the ranking of the 20 best and 20 worst days was different by one date each between the base case and the scenario case. This means that on one day of the 20 worst visibility days in the base case, the visibility improved enough due to the removal of emissions associated with the seven Texas point sources that that day was no longer one of the 20 worst days when the scenario case was ranked. For the 20 best visibility days at Caney Creek, a single day showed a big enough improvement in visibility (haze index) due to the removal of the emissions in the scenario case that that day moved into the 20 best visibility days, displacing a different date. All of the other three Class 1 areas had the same 40 dates used for the base case and the scenario case average calculations.

Table 3. Average haze index for the 20 best and 20 worst visibility days for the base case, the scenario case, the difference between the averages and the number of single day differences greater than 0.5 dv for each of the four Class 1 Area Monitor Sites.

| Four Texas Coal Plants and Three Other Texas Point Sources Zero'd Out | Basecase 20 Worst Days Average Haze Index (dv) | Scenario Case 20 Worst Days Average Haze Index (dv) | Average Difference Worst (dv) | Basecase 20 Best Days Average Haze Index (dv) | Scenario Case 20 Best Days Average Haze Index (dv) | Average Difference Best (dv) | # days with Single Day Impact > 0.5 dv |
|---|---|---|---|---|---|---|---|
| Big Bend NP | 18.58 | 18.31 | -0.27 | 2.56 | 2.55 | -0.01 | 7 |
| Caney Creek | 26.66 | 26.48 | -0.18 | 8.26 | 7.81 | -0.45 | 59 |
| Guadalupe Mountains NP | 15.76 | 15.48 | -0.28 | 3.08 | 3.07 | -0.01 | 9 |
| Wichita Mountains | 24.53 | 24.40 | -0.12 | 6.54 | 6.54 | -0.01 | 26 |

The results shown in Table 3 indicate that the largest impact in visibility due to the removal of emissions from the seven Texas point sources of interest occurs on clear days at Caney Creek wilderness area. Of the four Class 1 areas evaluated in this study, Caney Creek is the closest to Northeast Texas where the seven point sources are located.

**Tables 4 through 7** below present the date, the base case and scenario case values and difference in visibility due to the scenario case, for the 20 best and 20 worst visibility days, based on the base case haze index, for the Big Bend, Caney Creek, Guadalupe Mountains, and Wichita Mountains respectively. A negative change in the Haze Index due to the Scenario Case indicates an improvement in visibility when the emissions associated with the seven Texas facilities of interest are removed.

Table 4. Date, base case haze index, scenario case haze index and difference for the 20 best and 20 worst visibility days, based on the base case haze index, for Big Bend National Park.

| 20 Worst Visibility Days Ranked by Base case | | | | | 20 Best Visibility Days Ranked by Base case | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank by Base Case Haze Index | Date | Big Bend Base Case Haze Index (dv) | Big Bend Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) | Rank by Base Case Haze Index | Date | Big Bend Base Case Haze Index (dv) | Big Bend Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) |
| 1 | 20051017 | 25.46 | 25.33 | -0.13 | 20 | 20050221 | 3.24 | 3.24 | 0.00 |
| 2 | 20050219 | 20.98 | 20.67 | -0.31 | 19 | 20051230 | 3.23 | 3.23 | 0.00 |
| 3 | 20051016 | 20.76 | 20.12 | -0.64 | 18 | 20050306 | 3.15 | 3.15 | 0.00 |
| 4 | 20051014 | 20.68 | 19.68 | -1.00 | 17 | 20050727 | 3.10 | 3.10 | 0.00 |
| 5 | 20050130 | 19.40 | 19.35 | -0.05 | 16 | 20050717 | 3.03 | 2.99 | -0.03 |
| 6 | 20051030 | 18.98 | 18.98 | -0.01 | 15 | 20050819 | 3.01 | 3.01 | 0.00 |
| 7 | 20051015 | 18.97 | 17.66 | -1.32 | 14 | 20050729 | 2.81 | 2.79 | -0.01 |
| 8 | 20051031 | 18.56 | 18.55 | -0.01 | 13 | 20050530 | 2.78 | 2.70 | -0.07 |
| 9 | 20051219 | 18.02 | 18.00 | -0.02 | 12 | 20050714 | 2.77 | 2.73 | -0.05 |
| 10 | 20050212 | 18.01 | 17.84 | -0.17 | 11 | 20050722 | 2.76 | 2.76 | 0.00 |
| 11 | 20050923 | 17.86 | 17.62 | -0.24 | 10 | 20050818 | 2.69 | 2.69 | 0.00 |
| 12 | 20050218 | 17.70 | 17.22 | -0.47 | 9 | 20050918 | 2.67 | 2.67 | 0.00 |
| 13 | 20050131 | 17.59 | 17.00 | -0.59 | 8 | 20050716 | 2.65 | 2.60 | -0.06 |
| 14 | 20050210 | 17.27 | 17.18 | -0.10 | 7 | 20050529 | 2.51 | 2.51 | 0.00 |
| 15 | 20051220 | 17.24 | 17.16 | -0.08 | 6 | 20050719 | 2.36 | 2.36 | 0.00 |
| 16 | 20050104 | 17.12 | 17.12 | 0.00 | 5 | 20050726 | 2.25 | 2.25 | 0.00 |
| 17 | 20050103 | 17.10 | 17.10 | 0.00 | 4 | 20050806 | 2.05 | 2.05 | 0.00 |
| 18 | 20050908 | 16.95 | 16.88 | -0.08 | 3 | 20050725 | 1.49 | 1.49 | 0.00 |
| 19 | 20050119 | 16.72 | 16.61 | -0.11 | 2 | 20050820 | 1.44 | 1.44 | 0.00 |
| 20 | 20050906 | 16.13 | 16.12 | -0.01 | 1 | 20050718 | 1.25 | 1.24 | 0.00 |

Table 5. Date, base case haze index, scenario case haze index and difference for the 20 best and 20 worst visibility days, based on the base case haze index, for Caney Creek Wilderness Area.

| 20 Worst Visibility Days Ranked by Base case | | | | | 20 Best Visibility Days Ranked by Base case | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank by Base Case Haze Index | Date | Caney Creek Base Case Haze Index (dv) | Caney Creek Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) | Rank by Base Case Haze Index | Date | Caney Creek Base Case Haze Index (dv) | Caney Creek Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) |
| 1 | 20050203 | 33.28 | 33.28 | 0.00 | 20 | 20050820 | 9.00 | 8.66 | -0.34 |
| 2 | 20050208 | 30.30 | 30.22 | -0.08 | 19 | 20050705 | 8.98 | 8.86 | -0.12 |
| 3 | 20050110 | 30.28 | 28.96 | -1.32 | 18 | 20050718 | 8.95 | 6.82 | -2.12 |
| 4 | 20050204 | 30.24 | 30.24 | 0.00 | 17 | 20051007 | 8.94 | 8.93 | -0.01 |
| 5 | 20050222 | 29.53 | 29.29 | -0.25 | 16 | 20050424 | 8.93 | 8.93 | 0.00 |
| 6 | 20050909 | 27.29 | 27.28 | 0.00 | 15 | 20050812 | 8.90 | 8.31 | -0.59 |
| 7 | 20050209 | 27.28 | 27.21 | -0.06 | 14 | 20051229 | 8.80 | 8.80 | 0.00 |
| 8 | 20050326 | 27.16 | 27.11 | -0.05 | 13 | 20051211 | 8.70 | 8.70 | 0.01 |
| 9 | 20050201 | 26.94 | 26.94 | 0.00 | 12 | 20050815 | 8.65 | 7.30 | -1.35 |
| 10 | 20050130 | 25.87 | 25.86 | 0.00 | 11 | 20051008 | 8.57 | 8.56 | 0.00 |
| 11 | 20051121 | 25.49 | 25.49 | 0.00 | 10 | 20050821 | 8.50 | 8.13 | -0.38 |
| 12 | 20051011 | 25.28 | 25.27 | -0.01 | 9 | 20050719 | 8.38 | 7.73 | -0.65 |
| 13 | 20050131 | 25.06 | 25.05 | -0.01 | 8 | 20050915 | 8.36 | 7.84 | -0.52 |
| 14 | 20050223 | 24.98 | 24.80 | -0.18 | 7 | 20051212 | 8.33 | 8.33 | 0.00 |
| 15 | 20051012 | 24.90 | 24.82 | -0.08 | 6 | 20050613 | 8.26 | 7.41 | -0.85 |
| 16 | 20050325 | 24.46 | 24.22 | -0.23 | 5 | 20050609 | 7.83 | 7.55 | -0.29 |
| 17 | 20050304 | 24.36 | 23.66 | -0.69 | 4 | 20050612 | 7.38 | 7.36 | -0.02 |
| 18 | 20050731 | 23.63 | 23.62 | -0.02 | 3 | 20050924 | 6.93 | 6.93 | 0.00 |
| 19 | 20050109 | 23.54 | 22.59 | -0.95 | 2 | 20050717 | 6.47 | 5.05 | -1.42 |
| 20 | 20050408 | 23.32 | 23.27 | -0.05 | 1 | 20050925 | 6.40 | 6.40 | 0.00 |

Table 6. Date, base case haze index, scenario case haze index and difference for the 20 best and 20 worst visibility days, based on the base case haze index, for Guadalupe Mountains National Park.

| 20 Worst Visibility Days Ranked by Base case | | | | | 20 Best Visibility Days Ranked by Base case | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank by Base Case Haze Index | Date | Guadalupe Mnts Base Case Haze Index (dv) | Guadalupe Mnts Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) | Rank by Base Case Haze Index | Date | Guadalupe Mnts Base Case Haze Index (dv) | Guadalupe Mnts Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) |
| 1 | 20050924 | 18.22 | 17.20 | -1.02 | 20 | 20050109 | 3.97 | 3.98 | 0.00 |
| 2 | 20050224 | 17.88 | 17.85 | -0.04 | 19 | 20051210 | 3.94 | 3.94 | 0.00 |
| 3 | 20050202 | 16.88 | 16.88 | 0.00 | 18 | 20050720 | 3.85 | 3.85 | 0.00 |
| 4 | 20050910 | 16.78 | 16.65 | -0.12 | 17 | 20051117 | 3.75 | 3.75 | 0.00 |
| 5 | 20051014 | 16.65 | 15.55 | -1.10 | 16 | 20051121 | 3.68 | 3.68 | 0.01 |
| 6 | 20050201 | 16.30 | 16.27 | -0.03 | 15 | 20050723 | 3.66 | 3.56 | -0.10 |
| 7 | 20050909 | 16.26 | 16.07 | -0.19 | 14 | 20051123 | 3.52 | 3.52 | 0.00 |
| 8 | 20051018 | 16.17 | 15.98 | -0.18 | 13 | 20050828 | 3.37 | 3.34 | -0.03 |
| 9 | 20051015 | 16.03 | 14.98 | -1.04 | 12 | 20050528 | 3.36 | 3.27 | -0.09 |
| 10 | 20050908 | 16.01 | 15.90 | -0.11 | 11 | 20051122 | 3.24 | 3.24 | 0.00 |
| 11 | 20050225 | 15.43 | 15.41 | -0.02 | 10 | 20051206 | 3.12 | 3.12 | 0.00 |
| 12 | 20050906 | 15.33 | 15.31 | -0.01 | 9 | 20050103 | 2.99 | 2.99 | 0.00 |
| 13 | 20050219 | 14.87 | 14.32 | -0.56 | 8 | 20050710 | 2.88 | 2.86 | -0.02 |
| 14 | 20050210 | 14.85 | 14.79 | -0.06 | 7 | 20051128 | 2.85 | 2.84 | 0.00 |
| 15 | 20051017 | 14.83 | 14.32 | -0.51 | 6 | 20051129 | 2.67 | 2.67 | 0.00 |
| 16 | 20050131 | 14.74 | 14.52 | -0.22 | 5 | 20051228 | 2.65 | 2.65 | 0.00 |
| 17 | 20050907 | 14.69 | 14.60 | -0.09 | 4 | 20050213 | 2.40 | 2.40 | 0.00 |
| 18 | 20050218 | 14.44 | 14.38 | -0.06 | 3 | 20051229 | 2.26 | 2.25 | 0.00 |
| 19 | 20050905 | 14.42 | 14.26 | -0.16 | 2 | 20050721 | 1.70 | 1.70 | 0.00 |
| 20 | 20050212 | 14.39 | 14.27 | -0.11 | 1 | 20050722 | 1.69 | 1.69 | 0.00 |

Table 7. Date, base case haze index, scenario case haze index and difference for the 20 best and 20 worst visibility days, based on the base case haze index, for Wichita Mountains.

| 20 Worst Visibility Days Ranked by Base case | | | | | 20 Best Visibility Days Ranked by Base case | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank by Base Case Haze Index | Date | Wichita Mnts Base Case Haze Index (dv) | Witchita Mnts Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) | Rank by Base Case Haze Index | Date | Wichita Mnts Base Case Haze Index (dv) | Witchita Mnts Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) |
| 1 | 20050202 | 29.69 | 29.69 | 0.00 | 20 | 20051211 | 7.56 | 7.56 | 0.00 |
| 2 | 20050222 | 28.34 | 28.17 | -0.16 | 19 | 20050821 | 7.51 | 7.51 | 0.00 |
| 3 | 20050201 | 26.67 | 26.67 | 0.00 | 18 | 20051216 | 7.49 | 7.49 | 0.00 |
| 4 | 20050303 | 26.67 | 26.14 | -0.53 | 17 | 20051215 | 7.41 | 7.41 | -0.01 |
| 5 | 20050326 | 26.34 | 26.33 | -0.01 | 16 | 20050813 | 7.37 | 7.36 | -0.01 |
| 6 | 20050203 | 25.45 | 25.45 | 0.00 | 15 | 20050311 | 7.30 | 7.30 | 0.00 |
| 7 | 20050304 | 25.29 | 25.00 | -0.29 | 14 | 20050812 | 7.12 | 7.12 | 0.00 |
| 8 | 20050325 | 24.53 | 24.52 | -0.01 | 13 | 20050814 | 6.95 | 6.94 | 0.00 |
| 9 | 20050327 | 24.41 | 24.40 | -0.01 | 12 | 20050819 | 6.92 | 6.91 | -0.01 |
| 10 | 20050223 | 24.27 | 24.19 | -0.08 | 11 | 20050609 | 6.82 | 6.82 | 0.00 |
| 11 | 20050208 | 23.85 | 23.78 | -0.07 | 10 | 20051225 | 6.76 | 6.76 | 0.00 |
| 12 | 20050111 | 23.38 | 23.33 | -0.05 | 9 | 20050818 | 6.44 | 6.44 | 0.00 |
| 13 | 20050209 | 23.34 | 23.32 | -0.03 | 8 | 20051006 | 6.24 | 6.22 | -0.01 |
| 14 | 20050224 | 23.23 | 23.23 | 0.00 | 7 | 20050820 | 6.08 | 6.08 | 0.00 |
| 15 | 20050118 | 22.79 | 22.70 | -0.09 | 6 | 20050719 | 5.98 | 5.98 | 0.00 |
| 16 | 20050226 | 22.75 | 22.73 | -0.01 | 5 | 20050721 | 5.89 | 5.89 | 0.00 |
| 17 | 20050131 | 22.66 | 22.66 | 0.00 | 4 | 20050704 | 5.76 | 5.68 | -0.09 |
| 18 | 20050506 | 22.64 | 22.31 | -0.33 | 3 | 20050726 | 5.41 | 5.41 | 0.00 |
| 19 | 20050206 | 22.20 | 22.03 | -0.17 | 2 | 20050725 | 5.21 | 5.21 | 0.00 |
| 20 | 20050305 | 22.04 | 21.43 | -0.62 | 1 | 20050718 | 4.67 | 4.67 | 0.00 |

**Tables 8 through 11** below present the date, the base case and scenario case values and difference in visibility due to the scenario case, for the 20 largest and the 20 smallest changes in visibility between the base case and the scenario case haze indices, for the Big Bend, Caney Creek, Guadalupe Mountains, and Wichita Mountains respectively. For this study, "largest changes" refers to the biggest improvements in visibility due to the removal of emissions associated with seven Texas point sources, and is indicated by the largest negative changes in the haze index due to the scenario case. Also for this study, the "smallest changes" refers to the smallest improvements in visibility due to the removal of emissions associated with seven Texas point sources. The "smallest changes" can also include both zero change, and decreases in visibility due to the removal of emissions from the seven Texas point sources, the latter would be indicated by positive changes in the haze index due to the scenario case.

As opposed to the results ranked by base case haze index as reported in Tables 4 through 7, the results in Tables 8 through 11 are ranked by the change in haze index between the base case and the scenario case to provide a clearer picture of the values of the haze index on days characterized by the largest and smallest changes in visibility due to the removal of emissions associated with the seven Texas point sources of interest.

Table 8. Date, base case haze index, scenario case haze index and difference for the 20 days with the largest and the 20 days with the smallest difference in visibility for Big Bend National Park.

| 20 Days with the Biggest Improvement in Visibility due to Scenario | | | | | 20 Days with the Smallest Change in Visibility due to Scenario | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank by Change in Haze Index Due to Scenario | Date | Big Bend Base Case Haze Index (dv) | Big Bend Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) | Rank by Change in Haze Index Due to Scenario | Date | Big Bend Base Case Haze Index (dv) | Big Bend Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) |
| 1 | 20051015 | 18.97 | 17.66 | -1.32 | 20 | 20050320 | 4.70 | 4.70 | 0.00 |
| 2 | 20051014 | 20.68 | 19.68 | -1.00 | 19 | 20050520 | 10.57 | 10.57 | 0.00 |
| 3 | 20050924 | 14.27 | 13.38 | -0.89 | 18 | 20050701 | 4.51 | 4.52 | 0.00 |
| 4 | 20050902 | 11.01 | 10.34 | -0.67 | 17 | 20050411 | 4.98 | 4.98 | 0.00 |
| 5 | 20051016 | 20.76 | 20.12 | -0.64 | 16 | 20050917 | 4.62 | 4.63 | 0.00 |
| 6 | 20050131 | 17.59 | 17.00 | -0.59 | 15 | 20051114 | 7.71 | 7.72 | 0.00 |
| 7 | 20050531 | 5.85 | 5.27 | -0.58 | 14 | 20051202 | 5.76 | 5.77 | 0.00 |
| 8 | 20050218 | 17.70 | 17.22 | -0.47 | 13 | 20050614 | 7.40 | 7.40 | 0.00 |
| 9 | 20050118 | 14.02 | 13.59 | -0.43 | 12 | 20050612 | 8.39 | 8.40 | 0.00 |
| 10 | 20050731 | 7.35 | 6.94 | -0.41 | 11 | 20050302 | 6.20 | 6.20 | 0.00 |
| 11 | 20050925 | 8.86 | 8.47 | -0.39 | 10 | 20051113 | 3.58 | 3.58 | 0.00 |
| 12 | 20050801 | 12.23 | 11.88 | -0.35 | 9 | 20050613 | 7.10 | 7.10 | 0.00 |
| 13 | 20050117 | 11.16 | 10.84 | -0.32 | 8 | 20050114 | 4.65 | 4.66 | 0.01 |
| 14 | 20050219 | 20.98 | 20.67 | -0.31 | 7 | 20051216 | 8.08 | 8.09 | 0.01 |
| 15 | 20050316 | 12.36 | 12.07 | -0.29 | 6 | 20051103 | 5.46 | 5.47 | 0.01 |
| 16 | 20050903 | 8.69 | 8.41 | -0.28 | 5 | 20050702 | 6.17 | 6.18 | 0.01 |
| 17 | 20050923 | 17.86 | 17.62 | -0.24 | 4 | 20050322 | 4.79 | 4.80 | 0.01 |
| 18 | 20050504 | 14.34 | 14.13 | -0.20 | 3 | 20050115 | 6.99 | 7.01 | 0.01 |
| 19 | 20051221 | 14.27 | 14.07 | -0.20 | 2 | 20051215 | 6.41 | 6.43 | 0.02 |
| 20 | 20051025 | 10.47 | 10.28 | -0.19 | 1 | 20050301 | 7.48 | 7.52 | 0.03 |

Table 9. Date, base case haze index, scenario case haze index and difference for the 20 days with the largest and the 20 days with the smallest difference in visibility for Caney Creek Wilderness Area.

| 20 Days with the Biggest Improvement in Visibility due to Scenario | | | | | 20 Days with the Smallest Change in Visibility due to Scenario | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank by Change in Haze Index Due to Scenario | Date | Caney Creek Base Case Haze Index (dv) | Caney Creek Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) | Rank by Change in Haze Index Due to Scenario | Date | Caney Creek Base Case Haze Index (dv) | Caney Creek Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) |
| 1 | 20050810 | 18.22 | 15.25 | -2.97 | 20 | 20050424 | 8.93 | 8.93 | 0.00 |
| 2 | 20050421 | 19.15 | 16.60 | -2.55 | 19 | 20050924 | 6.93 | 6.93 | 0.00 |
| 3 | 20051108 | 14.43 | 12.16 | -2.27 | 18 | 20050925 | 6.40 | 6.40 | 0.00 |
| 4 | 20050718 | 8.95 | 6.82 | -2.12 | 17 | 20051102 | 10.38 | 10.38 | 0.00 |
| 5 | 20050422 | 18.14 | 16.10 | -2.04 | 16 | 20050316 | 18.58 | 18.58 | 0.00 |
| 6 | 20050510 | 18.44 | 16.57 | -1.86 | 15 | 20050203 | 33.28 | 33.28 | 0.00 |
| 7 | 20050104 | 19.56 | 18.02 | -1.54 | 14 | 20051225 | 15.12 | 15.12 | 0.00 |
| 8 | 20050524 | 17.76 | 16.33 | -1.43 | 13 | 20051023 | 13.63 | 13.63 | 0.00 |
| 9 | 20050717 | 6.47 | 5.05 | -1.42 | 12 | 20050311 | 11.65 | 11.65 | 0.00 |
| 10 | 20050725 | 13.60 | 12.24 | -1.36 | 11 | 20051116 | 11.08 | 11.08 | 0.00 |
| 11 | 20050608 | 9.72 | 8.37 | -1.36 | 10 | 20051122 | 12.46 | 12.46 | 0.00 |
| 12 | 20050815 | 8.65 | 7.30 | -1.35 | 9 | 20050106 | 20.34 | 20.34 | 0.00 |
| 13 | 20050110 | 30.28 | 28.96 | -1.32 | 8 | 20050127 | 18.52 | 18.52 | 0.00 |
| 14 | 20050213 | 17.16 | 15.89 | -1.27 | 7 | 20051209 | 16.32 | 16.32 | 0.00 |
| 15 | 20050701 | 14.69 | 13.43 | -1.27 | 6 | 20051117 | 11.75 | 11.75 | 0.00 |
| 16 | 20051103 | 14.11 | 12.87 | -1.24 | 5 | 20051217 | 9.11 | 9.11 | 0.00 |
| 17 | 20050724 | 12.87 | 11.65 | -1.21 | 4 | 20051208 | 20.20 | 20.20 | 0.00 |
| 18 | 20051109 | 15.20 | 14.02 | -1.18 | 3 | 20050123 | 14.93 | 14.93 | 0.00 |
| 19 | 20051227 | 16.78 | 15.61 | -1.16 | 2 | 20051229 | 8.80 | 8.80 | 0.00 |
| 20 | 20050818 | 11.70 | 10.60 | -1.10 | 1 | 20051211 | 8.70 | 8.70 | 0.01 |

Table 10. Date, base case haze index, scenario case haze index and difference for the 20 days with the largest and the 20 days with the smallest difference in visibility for Guadalupe Mountains National Park.

| 20 Days with the Biggest Improvement in Visibility due to Scenario | | | | | 20 Days with the Smallest Change in Visibility due to Scenario | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank by Change in Haze Index Due to Scenario | Date | Guadalupe Mnts Base Case Haze Index (dv) | Guadalupe Mnts Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) | Rank by Change in Haze Index Due to Scenario | Date | Guadalupe Mnts Base Case Haze Index (dv) | Guadalupe Mnts Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) |
| 1 | 20051014 | 16.65 | 15.55 | -1.10 | 20 | 20050703 | 7.36 | 7.36 | 0.00 |
| 2 | 20051015 | 16.03 | 14.98 | -1.04 | 19 | 20051210 | 3.94 | 3.94 | 0.00 |
| 3 | 20050924 | 18.22 | 17.20 | -1.02 | 18 | 20050720 | 3.85 | 3.85 | 0.00 |
| 4 | 20050902 | 11.90 | 11.27 | -0.62 | 17 | 20051221 | 5.36 | 5.36 | 0.00 |
| 5 | 20050801 | 10.57 | 9.99 | -0.58 | 16 | 20050114 | 4.54 | 4.54 | 0.00 |
| 6 | 20050516 | 6.03 | 5.45 | -0.57 | 15 | 20050413 | 7.26 | 7.27 | 0.00 |
| 7 | 20050219 | 14.87 | 14.32 | -0.56 | 14 | 20051130 | 4.05 | 4.06 | 0.01 |
| 8 | 20050903 | 7.69 | 7.14 | -0.55 | 13 | 20051121 | 3.68 | 3.68 | 0.01 |
| 9 | 20051017 | 14.83 | 14.32 | -0.51 | 12 | 20051001 | 5.35 | 5.36 | 0.01 |
| 10 | 20050806 | 5.82 | 5.33 | -0.49 | 11 | 20051118 | 8.42 | 8.43 | 0.01 |
| 11 | 20050904 | 12.39 | 11.95 | -0.44 | 10 | 20051225 | 4.54 | 4.55 | 0.01 |
| 12 | 20050802 | 9.51 | 9.09 | -0.42 | 9 | 20051120 | 4.31 | 4.32 | 0.01 |
| 13 | 20050731 | 6.39 | 5.98 | -0.40 | 8 | 20050702 | 7.86 | 7.86 | 0.01 |
| 14 | 20051016 | 9.94 | 9.60 | -0.34 | 7 | 20050410 | 4.78 | 4.79 | 0.01 |
| 15 | 20050118 | 13.49 | 13.16 | -0.33 | 6 | 20051010 | 6.36 | 6.37 | 0.01 |
| 16 | 20050803 | 7.91 | 7.61 | -0.31 | 5 | 20051226 | 5.14 | 5.15 | 0.01 |
| 17 | 20050130 | 11.89 | 11.62 | -0.28 | 4 | 20051126 | 7.24 | 7.25 | 0.01 |
| 18 | 20050601 | 9.97 | 9.70 | -0.27 | 3 | 20050629 | 7.79 | 7.80 | 0.01 |
| 19 | 20050808 | 9.16 | 8.89 | -0.27 | 2 | 20050110 | 4.98 | 4.99 | 0.02 |
| 20 | 20050825 | 8.71 | 8.44 | -0.27 | 1 | 20050228 | 8.74 | 8.79 | 0.05 |

Table 11. Date, base case haze index, scenario case haze index and difference for the 20 days with the largest and the 20 days with the smallest difference in visibility for Wichita Mountains.

| 20 Days with the Biggest Improvement in Visibility due to Scenario | | | | | 20 Days with the Smallest Change in Visibility due to Scenario | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank by Change in Haze Index Due to Scenario | Date | Wichita Mnts Base Case Haze Index (dv) | Witchita Mnts Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) | Rank by Change in Haze Index Due to Scenario | Date | Wichita Mnts Base Case Haze Index (dv) | Witchita Mnts Scenario Case Haze Index (dv) | Change in Haze Index Due to Scenario (dv) |
| 1 | 20050529 | 17.83 | 16.46 | -1.36 | 20 | 20050315 | 17.02 | 17.02 | 0.00 |
| 2 | 20050602 | 16.70 | 15.59 | -1.11 | 19 | 20050421 | 14.62 | 14.62 | 0.00 |
| 3 | 20050531 | 12.14 | 11.03 | -1.11 | 18 | 20051209 | 15.01 | 15.01 | 0.00 |
| 4 | 20050703 | 10.55 | 9.53 | -1.02 | 17 | 20050310 | 9.72 | 9.72 | 0.00 |
| 5 | 20050618 | 8.75 | 7.79 | -0.96 | 16 | 20051205 | 19.56 | 19.56 | 0.00 |
| 6 | 20050603 | 13.70 | 12.79 | -0.90 | 15 | 20050102 | 21.48 | 21.49 | 0.00 |
| 7 | 20050808 | 15.05 | 14.19 | -0.86 | 14 | 20050316 | 20.98 | 20.98 | 0.00 |
| 8 | 20050804 | 13.51 | 12.74 | -0.77 | 13 | 20051211 | 7.56 | 7.56 | 0.00 |
| 9 | 20050517 | 15.35 | 14.59 | -0.76 | 12 | 20050204 | 19.85 | 19.85 | 0.00 |
| 10 | 20050516 | 14.80 | 14.06 | -0.74 | 11 | 20051201 | 10.63 | 10.63 | 0.00 |
| 11 | 20050810 | 14.55 | 13.82 | -0.73 | 10 | 20050607 | 8.97 | 8.97 | 0.00 |
| 12 | 20051010 | 13.74 | 13.01 | -0.73 | 9 | 20051229 | 7.94 | 7.94 | 0.00 |
| 13 | 20050802 | 15.08 | 14.37 | -0.71 | 8 | 20050123 | 10.33 | 10.33 | 0.00 |
| 14 | 20051028 | 18.68 | 18.04 | -0.63 | 7 | 20050719 | 5.98 | 5.98 | 0.00 |
| 15 | 20050923 | 19.29 | 18.67 | -0.62 | 6 | 20051208 | 13.80 | 13.81 | 0.00 |
| 16 | 20050807 | 13.78 | 13.16 | -0.62 | 5 | 20050701 | 10.07 | 10.08 | 0.00 |
| 17 | 20050305 | 22.04 | 21.43 | -0.62 | 4 | 20050721 | 5.89 | 5.89 | 0.00 |
| 18 | 20050619 | 12.85 | 12.27 | -0.58 | 3 | 20051228 | 7.64 | 7.64 | 0.00 |
| 19 | 20050623 | 19.66 | 19.08 | -0.58 | 2 | 20051210 | 14.44 | 14.45 | 0.01 |
| 20 | 20050811 | 10.43 | 9.87 | -0.56 | 1 | 20051117 | 12.42 | 12.43 | 0.01 |

The dates with the largest increase in visibility (decrease in haze index) due to the removal of emissions associated with the seven Texas point sources at each Class 1 area are: October 14$^{th}$ and 15$^{th}$ at Big Bend and Guadalupe Mountains, August 10$^{th}$ at Caney Creek, and May 29$^{th}$ at

Wichita Mountains. **Table 12** below shows the light extinction coefficients for each of the particulate species plus gaseous $NO_2$ on each of those dates, for the corresponding Class 1 Area. On each of those dates, the largest contribution and impact in the haze index is due to the modeled concentrations of particulate sulfate at each site.

The purpose for presenting the data in Table 12 is to make the case that the relative spatial distribution of the modeled change in visibility at those locations on those dates can be approximately represented by the spatial distribution of the change in particulate sulfate on those dates. **Figures 3 a through d** show the change in modeled concentrations of particulate sulfate (scenario case – base case in $\mu g/m^3$) due to the removal of emissions associated with the seven Texas point sources on October 15th, August 10th, October 14th, and May 29th respectively. Areas of negative sulfate concentrations indicate decreases in particulate sulfate (and therefore improvements in visibility) due to the removal of emissions.

Table 12. The light extinction coefficients (Mm-1) of each particulate species plus gaseous $NO_2$, for the dates characterized by the largest increase in visibility (decrease in haze index) due to the removal of emissions associated with seven Texas point sources, at each of the four Class 1 areas.

| Class 1 Area | | Date | $b_{Sulfate}$ | $b_{Nitrate}$ | $b_{OMC}$ | $b_{EC}$ | $b_{Soil} + b_{CM}$ | $b_{NO2}$ |
|---|---|---|---|---|---|---|---|---|
| Big Bend NP | Base: | 20051015 | 48.975 | 0.014 | 2.252 | 2.429 | 2.997 | 0 |
| Big Bend NP | Scenario: | 20051015 | 40.74 | 0.097 | 2.228 | 2.419 | 2.964 | 0 |
| Caney Creek | Base: | 20050810 | 43.053 | 1.299 | 3.465 | 1.26 | 1.463 | 0.33 |
| Caney Creek | Scenario: | 20050810 | 28.34 | 0.456 | 3.357 | 1.239 | 1.393 | 0.183 |
| Guadalupe Mountains NP | Base: | 20051014 | 35.146 | 0.329 | 2.355 | 2.481 | 3.294 | 0.257 |
| Guadalupe Mountains NP | Scenario: | 20051014 | 29.45 | 0.564 | 2.343 | 2.471 | 3.265 | 0.257 |
| Wichita Mountains | Base: | 20050529 | 41.796 | 0.184 | 1.599 | 1.386 | 3.127 | 0.367 |
| Wichita Mountains | Scenario: | 20050529 | 34.186 | 0.248 | 1.593 | 1.38 | 3.11 | 0.367 |

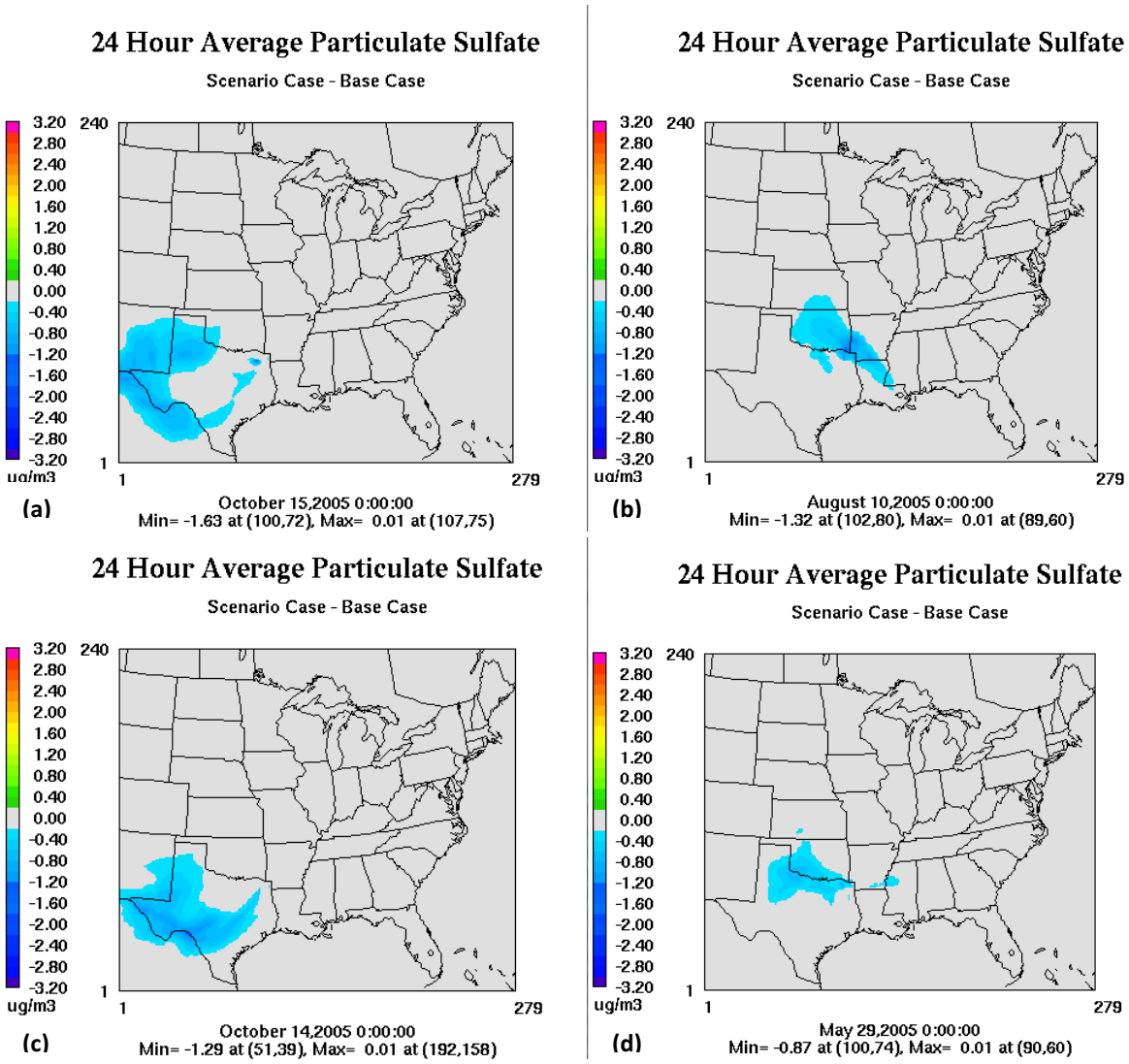



Figure 3 (a-d). Difference in modeled particulate sulfate concentrations (Scenario case – base case, µg/m$^3$) due to the removal of emissions associated with the seven Texas point sources, on October 15$^{th}$, August 10$^{th}$, October 14$^{th}$, and May 29$^{th}$.

## V. Summary

The objectives of the modeling study described in this report were to estimate the impact on visibility due to emissions from four existing coal-fired power plants, plus three additional BART-eligible point sources, all located in the state of Texas, at four Class 1 Areas in Texas, Arkansas and Oklahoma. Visibility was evaluated using an updated IMPROVE equation recommended by the U.S.EPA for visibility studies.

Two year-long air quality modeling simulations were run: The first simulation was a base case representing conditions projected to 2014 with Cross State Air Pollution Rule proposed controls. The second simulation was run just like the first with the only change being the removal of all emissions associated with seven large point sources in Northeast Texas.

The Haze Index, a measure of visibility in deciviews, was calculated for each day of the modeling year. The top 20 best and worst visibility days were identified for each simulation at each of the four Class 1 areas. The average of the top 20 best days was calculated and the difference between the scenario case and the base case represents the estimated impact of the emissions from the seven point sources in Texas on visibility on good days at that site. The same calculation was done to evaluate the impact of those seven sources on bad visibility days at each site.

The average modeled impact of those seven sources on good visibility days ranged from 0.01 deciviews (at Big Bend, Guadalupe Mountains, and Wichita Mountains) to 0.45 deciviews at Caney Creek. The average modeled impact of those seven sources on bad visibility days ranged from 0.12 deciviews at Wichita Mountains to 0.28 deciviews at Guadalupe Mountains.

## VI. References


CMAS, 2009. SMOKE v2.6 User's Manual. The University of North Carolina at Chapel Hill. http://www.smoke-model.org/index.cfm

ENVIRON, 2010. User's Guide: Comprehensive Air Quality Model with Extensions. Version 5.3. www.camx.com

EPA, 2007. Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze. Office of Air Quality Planning and Standards. EPA-454/B-07-002. April 2007. http://www.epa.gov/scram001/guidance/guide/final-03-pm-rh-guidance.pdf

EPA, 2011a. Emissions Inventory Files. EPA ftp site. FTP site Accessed July 2011. ftp://ftp.epa.gov/EmisInventory/2005v4_2/2014emis

EPA, 2011b. National Ambient Air Quality Standards. Office of Air and Radiation. Accessed Nov. 2011. http://epa.gov/air/criteria.html

EPA, 2011c. Cross-State Air Pollution Rule. Office of Air and Radiation. Website accessed July 2011. http://www.epa.gov/crossstaterule/

EPA, 2011d. Technical Support Document for the final Transport Rule: Emissions Inventory Final Rule TSD. Docket ID No. EPA-HQ-OAR-2009-0491. http://epa.gov/crossstaterule/pdfs/EmissionsInventory.pdf

EPA, 2011e. Air Quality Modeling Final Rule Technical Support Document. Office of Air Quality Planning and Standards. June 2011. http://www.epa.gov/airtransport/pdfs/AQModeling.pdf

EPA, 2011f. Transport Rule Preamble. Accessed January 2012. http://www.gpo.gov/fdsys/pkg/FR-2010-08-02/pdf/2010-17007.pdf#page=1

Grell, G., J. Dudhia, and D. Stauffer, 1994: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR/TN-398+STR., 138 pp, National Center for Atmospheric Research, Boulder CO.

Pitchford, M.; Maim, W.; Schichtel, B.; Kumar, N.; Lowenthal, D.; Hand, J. 2007. Revised algorithm for estimating light extinction from IMPROVE particle speciation data. J Air Waste Manag Assoc. 57(11): 1326-36.

VIEWS, 2012. Views 2.0 Air quality data, Tools and Resources. Assessed February 2012. http://views.cira.colostate.edu/web/

# EXHIBIT 20

Observer Reports

- Canadian
- Midcontinent
- Northeast
- Rockies
- SE/Gulf
- Texas
- West

# Texas Observer

Texas is the No. 1 state when it comes to natural gas in the U.S., with 25% of total production. The state also is one of the largest consumers of gas, accounting for 20% of the total market. With a number of key pricing hubs and storage facilities, an understanding of the Texas market is crucial to any assessment of the national market.

With its forward-looking view, BENTEK's daily ***Texas Observer***™ is the most accurate supplier of information on the Texas gas market available in the industry. Based on its industry-leading, proprietary, flow-data-gathering technology and modeling, BENTEK offers the best forecasts of Texas production and storage, which are the clearest views of Texas you can access. BENTEK analysts, who are available to answer your questions, detail the impact Texas has on the U.S. market.

The *Texas Observer* includes a regional supply/demand balance, a recap of pipeline utilization, receipts and deliveries into intrastate pipelines and a demand forecast for the region. It also includes an assessment of production, storage, rig counts and ERCOT power load.

Related Links

- CellCAST
- SE/Gulf
- Storage
- Supply/Demand

Texas Observer

Request information about Texas Observer.

More Info

 © Copyright 2013 BENTEK Energy 

# EXHIBIT 21

Bloomberg.com | Businessweek.com | Bloomberg TV | Premium | Register | Sign In

MARKET SNAPSHOT

U.S. EUROPE ASIA

| | | | |
|---|---|---|---|
| DJIA | 15,164.96 | 35.29 | 0.23% |
| S&P 500 | 1,692.21 | 10.66 | 0.63% |
| NASDAQ | 3,801.77 | 30.29 | 0.80% |

Bloomberg

Search News, Quotes and Opinion

Our Company | Professional | Anywhere

HOME QUICK NEWS OPINION MARKET DATA PERSONAL FINANCE TECH POLITICS SUSTAINABILITY TV VIDEO RADIO

# BENTEK: Eagle Ford Crude Oil Production Expected to Grow

BENTEK: Eagle Ford Crude Oil Production Expected to Grow Fivefold in Five Years; Both Gas and NGLs Will Jump 1.5x.

Oil, gas and NGL production from the liquids-rich Eagle Ford Shale in South Texas set to boom, due to a highly attractive oil/condensate play, a solid base of midstream infrastructure, extensive planned infrastructure expansions
and proximity to some of the largest energy markets in North America.

Business Wire

EVERGREEN, Colo. -- April 18, 2011

BENTEK Energy has just issued a Market Alert providing an analysis of shale oil, wet gas, natural gas liquids (NGL) and dry gas production growth anticipated from the Eagle Ford Shale in South Texas over the next five years.
While there are multiple rapidly-growing unconventional oil and gas plays across the U.S., the Eagle Ford Shale in South Texas, currently the fourth most active play in the nation, stands above the crowd due to its heavy liquids content in three primary producing regions.

“Horizontal drilling for oil has been highly successful in the northern part
of the play, with production expected to increase fivefold from current levels
of 71,000 barrels of oil per day (B/pd) to an average of 421,000 B/pd by 2015,” said BENTEK Managing Director E. Russell (Rusty) Braziel. “We are projecting that dry natural gas production, mostly located in the southern portion of the Eagle Ford, will increase from 1.4 billion cubic feet per day
(Bcf/d) to more than 3.5 Bcf/d by 2014. During the same period, NGL production

Advertisement

Advertisements

FOREX.com

Sponsored Links

New Shale Oil Discovery?
InvestmentU.com/Shale
Could be the biggest shale find in the lower 48 stats. Free Report.

Invest In Oil and Gas
www.breitlingoilandgas.com
Oil and Gas Investments. Diversify Your Portfolio!

from the central sector of the Eagle Ford is projected to grow from current levels of 103 million barrels per day (Mbbl/d) to almost 260 Mbbl/d."

BENTEK's Market Alert, Eagle Ford Shale - Deep in the Heart of Texas, notes that the Eagle Ford is primed for growth, thanks to the substantial foundation of gathering, transmission, processing and fractionation infrastructure in place. There also are a significant number of expansion projects either already under construction or planned for development over the next few years. About 2.4 Bcf/d of new gas gathering and transmission, 350,000 b/d of fractionation capacity and nearly 600,000 b/d of oil pipeline capacity is planned for development in the Eagle Ford before the end of 2012. BENTEK expects most of the significant infrastructure bottlenecks will be alleviated during this period, allowing production to grow rapidly.

Available markets also will play a role in Eagle Ford development – the Eagle Ford is next door to the nation's largest refining markets. Eagle Ford natural gas also has pipeline space to move east, north, west or south across the Mexican border. Mexico already is becoming an important destination. Eagle Ford NGLs are being produced in close proximity to the nation's benchmark NGL market at Mt. Belvieu. Gas production from this play has among the highest liquids content of any major unconventional play today in North America, and its proximity to these important markets will ensure an aggressive growth trajectory.

For more information about the Eagle Ford Shale – Deep in the Heart of Texas™ Market Alert, or any of BENTEK's regional production analysis reports, go to www.bentekenergy.com or call 1-888-251-1264. Learn more about BENTEK and meet with its analytics staff at BENPOSIUM.

About BENTEK Energy

BENTEK Energy is the leading energy markets information company. Based in Evergreen, CO, BENTEK brings customers the analytical tools and competitive intelligence needed to make time-critical, bottom-line decisions in today's natural gas, oil, liquids and power markets. Additional information about BENTEK Energy is available on the web at www.bentekenergy.com.

Contact:

For BENTEK Energy
Media:
Gretchen Weis, 713-385-8912
or
Company:

Nigeria Oil & Gas Report
BusinessMonitor.com/NigeriaOil&Gas
Download a Free Extract from the Latest Oil & Gas Report!

Advertisement

John Lange, 303-988-1320

Tweet 0 Share More Email Print

Sponsored Links

Bloomberg

RADIO LIVE TV

BLOOMBERG.COM News | Opinion | Markets | Personal Finance | Tech | Sustainability | TV | Video | Radio | Archives

ABOUT About Bloomberg | Careers | Advertising | Press Room | Trademarks | Terms of Service | Privacy Policy

SUPPORT AND CONTACT Customer Support Contact | Feedback | Help | Sitemap

STAY CONNECTED Twitter Facebook Linked In google+ StumbleUpon

BLOOMBERG TERMINAL

Professional

Anywhere

RELATED BLOOMBERG SITES

Bloomberg Businessweek
Bloomberg Institute
ブルームバーグ(日本語)
会社概要(日本語)
于彭博中国
Bloomberg Markets Magazine
Bloomberg Open Symbology
Bloomberg Link
Bloomberg Blog
Bloomberg Press

BLOOMBERG PREMIUM SERVICES

Bloomberg Briefs
Bloomberg Government
Bloomberg Law
Bloomberg BNA
Bloomberg New Energy Finance
Bloomberg Sports

MOBILE APPS

Bloomberg
Bloomberg Radio+
Bloomberg TV+
Bloomberg Businessweek+

©2013 BLOOMBERG L.P. ALL RIGHTS RESERVED.

Jobs by Indeed | Rate this Page | Made in NYC | Ad Choices

# EXHIBIT 22

# Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements

report by:
Al Armendariz, Ph.D.
Department of Environmental and Civil Engineering
Southern Methodist University
P.O. Box 750340
Dallas, Texas, 75275-0340

for:
Ramon Alvarez, Ph.D.
Environmental Defense Fund
44 East Avenue
Suite 304
Austin, Texas 78701

Version 1.1
January 26, 2009

# 1.0 EXECUTIVE SUMMARY

Natural gas production in the Barnett Shale region of Texas has increased rapidly since 1999, and as of June 2008, over 7700 oil and gas wells had been installed and another 4700 wells were pending. Gas production in 2007 was approximately 923 Bcf from wells in 21 counties. Natural gas is a critical feedstock to many chemical production processes, and it has many environmental benefits over coal as a fuel for electricity generation, including lower emissions of sulfur, metal compounds, and carbon dioxide. Nevertheless, oil and gas production from the Barnett Shale area can impact local air quality and release greenhouse gases into the atmosphere. The objectives of this study were to develop an emissions inventory of air pollutants from oil and gas production in the Barnett Shale area, and to identify cost-effective emissions control options.

Emission sources from the oil and gas sector in the Barnett Shale area were divided into point sources, which included compressor engine exhausts and oil/condensate tanks, as well as fugitive and intermittent sources, which included production equipment fugitives, well drilling and fracing engines, well completions, gas processing, and transmission fugitives. The air pollutants considered in this inventory were smog-forming compounds ($NO_x$ and VOC), greenhouse gases, and air toxic chemicals.

For 2009, emissions of smog-forming compounds from compressor engine exhausts and tanks were predicted to be approximately 96 tons per day (tpd) on an annual average, with peak summer emissions of 212 tpd. Emissions during the summer increase because of the effects of temperature on volatile organic compound emissions from storage tanks. Emissions of smog-forming compounds in 2009 from all oil and gas sources were estimated to be approximately 191 tpd on an annual average, with peak summer emissions of 307 tpd. The portion of those emissions originating from the 5-counties in the D-FW metropolitan area with significant oil and gas production was 165 tpd during the summer.

For comparison, 2009 emission inventories recently used by state and federal regulators estimated smog-forming emissions from all airports in the Dallas-Fort Worth metropolitan area to be 16 tpd. In addition, these same inventories had emission estimates for on-road motor vehicles (cars, trucks, etc.) in the 9-county Dallas-Fort Worth metropolitan area of 273 tpd. The portion of on-road motor vehicle emissions from the 5-counties in the D-FW metropolitan area with significant oil and gas production was 121 tpd, indicating that the oil and gas sector likely has greater emissions than motor vehicles in these counties.

The emission rate of air toxic compounds (like benzene and formaldehyde) from Barnett Shale activities was predicted to be approximately 6 tpd on an annual average, and 17 tpd during peak summer days. The largest contributors to air toxic emissions were the condensate tanks, followed by the engine exhausts.

In addition, predicted 2009 emissions of greenhouse gases like carbon dioxide and methane were approximately 33,000 tons per day of $CO_2$ equivalent. This is roughly equivalent to the expected greenhouse gas impact from two 750 MW coal-fired power plants. The largest contributors to the Barnett Shale greenhouse gas impact were $CO_2$ emissions from compressor engine exhausts and fugitive $CH_4$ emissions from all source types.

Cost effective control strategies are readily available that can substantially reduce emissions, and in some cases, reduce costs for oil and gas operators. These options include:

- use of "green completions" to capture methane and VOC compounds during well completions,
- phasing in electric motors as an alternative to internal-combustion engines to drive compressors,
- the control of VOC emissions from condensate tanks with vapor recovery units, and
- replacement of high-bleed pneumatic valves and fittings on the pipeline networks with no-bleed alternatives.

# 2.0 BACKGROUND

## 2.1 Barnett Shale Natural Gas Production

The Barnett Shale is a geological formation that the Texas Railroad Commission (RRC) estimates to extend 5000 square miles in parts of at least 21 Texas counties. The hydrocarbon productive region of the Barnett Shale has been designated as the Newark East Field, and large scale development of the natural gas resources in the field began in the late 1990's. Figure 1 shows the rapid and continuing development of natural gas from the Barnett Shale over the last 10 years.[1]

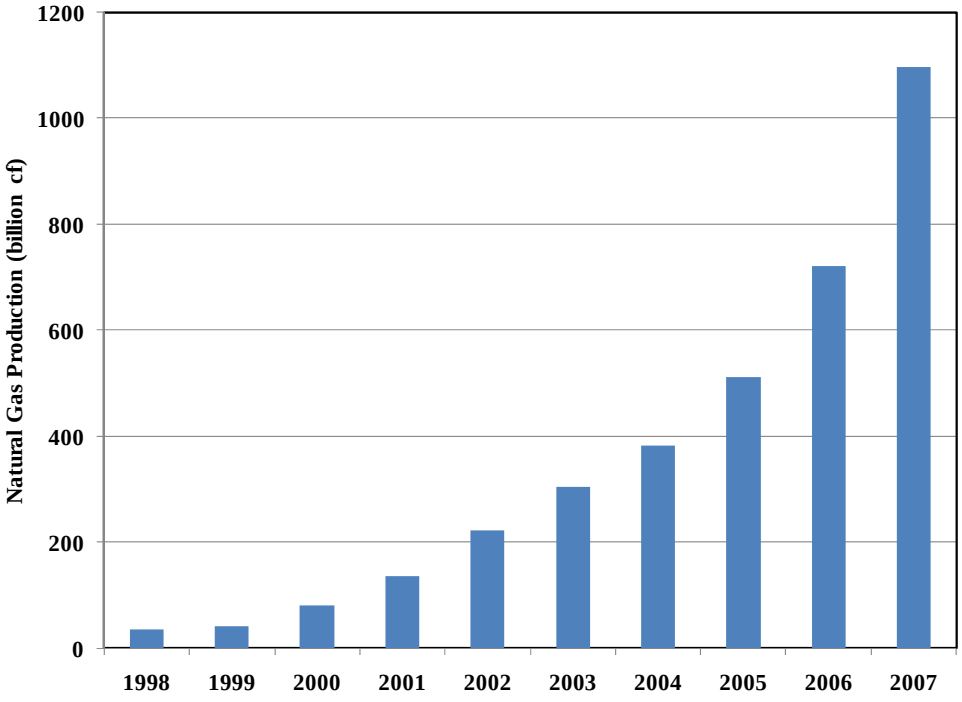



**Figure 1. Barnett Shale Natural Gas Production, 1998-2007.**

In addition to the recent development of the Barnett Shale, oil and gas production from other geologic formations and conventional sources in north central Texas existed before 1998 and continues to the present time. Production from the Barnett Shale is currently the dominant source of hydrocarbon production in the area from oil and gas activities in the area. Emission sources for all oil and gas activities are considered together in this report.

The issuance of new Barnett Shale area drilling permits has been following the upward trend of increasing natural gas production. The RRC issued 1112 well permits in 2004, 1629 in 2005, 2507 in 2006, 3657 in 2007, and they are on-track to issue over 4000 permits in 2008. The vast majority of the wells and permits are for natural gas production, but a small number of oil wells are also in operation or permitted in the area, and some oil wells co-produce casinghead gas. As of June 2008, over 7700 wells had been registered with the RRC, and the permit issuance rates are summarized in Table 1-1.[1] Annual oil, gas, condensate, and casinghead gas production rates for 21 counties in the Barnett Shale area are shown in Table 1-2.[1] The majority of Barnett Shale wells and well permits are located in six counties near the city of Fort Worth: Tarrant, Denton, Wise, Parker, Hood, and Johnson Counties. Figure 2 shows a RRC map of wells and well permits in the Barnett Shale.[2]

The top three gas producing counties in 2007 were Johnson, Tarrant and Wise, and the top three condensate producing counties were Wise, Denton, and Parker.

Nine (9) counties surrounding the cities of Fort Worth and Dallas have been designated by the U.S. EPA as the D-FW ozone nonattainment area (Tarrant, Denton, Parker, Johnson, Ellis, Collin, Dallas, Rockwall, and Kaufman ). Four of these counties (Tarrant, Denton, Parker, and Johnson) have substantial oil or gas production. In this report, these 9 counties are referred to as the D-FW metropolitan area. The areas outside these 9-counties with significant Barnett Shale oil or gas production are generally more rural counties to the south, west, and northwest of the city of Fort Worth. The counties inside and outside the D-FW metropolitan area with oil and gas production are listed in Table 1-3.

**Table 1-1. Barnett Shale Area Drilling Permits Issued, 2004-2008.[1]**

| year | new drilling permits |
|---|---|
| **2004** | 1112 |
| **2005** | 1629 |
| **2006** | 2507 |
| **2007** | 3657 |
| **2008** | 4000+ |

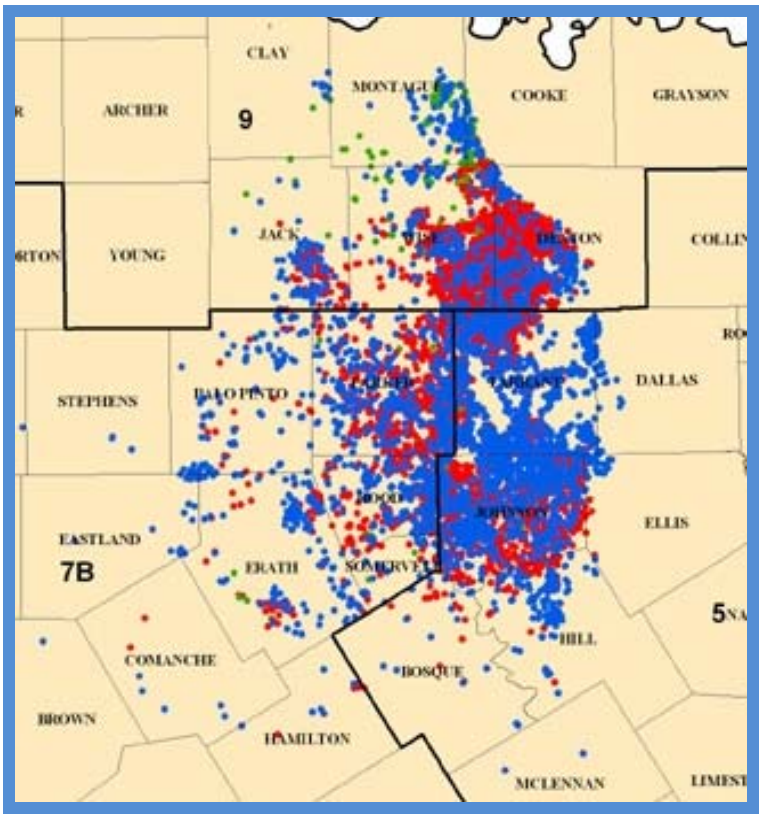
**Table 1-2. Hydrocarbon Production in the Barnett Shale Area in 2007.[1]**

| County | Gas Production (MCF) | Condensate (BBL) | Casinghead Gas (MCF) | Oil Production (BBL) |
|---|---|---|---|---|
| Johnson | 282,545,748 | 28,046 | 0 | 0 |
| Tarrant | 246,257,349 | 35,834 | 0 | 0 |
| Wise | 181,577,163 | 674,607 | 6,705,809 | 393,250 |
| Denton | 168,020,626 | 454,096 | 934,932 | 52,363 |
| Parker | 80,356,792 | 344,634 | 729,472 | 11,099 |
| Hood | 32,726,694 | 225,244 | 40,271 | 526 |
| Jack | 16,986,319 | 139,009 | 2,471,113 | 634,348 |
| Palo Pinto | 12,447,321 | 78,498 | 1,082,030 | 152,685 |
| Stephens | 11,149,910 | 56,183 | 3,244,894 | 2,276,637 |
| Hill | 7,191,823 | 148 | 0 | 0 |
| Erath | 4,930,753 | 11,437 | 65,425 | 5,073 |
| Eastland | 4,129,761 | 130,386 | 754,774 | 259,937 |
| Somervell | 4,018,269 | 6,317 | 0 | 0 |
| Ellis | 1,715,821 | 0 | 17,797 | 10 |
| Comanche | 560,733 | 1,584 | 52,546 | 7,055 |
| Cooke | 352,012 | 11,745 | 2,880,571 | 2,045,505 |
| Montague | 261,734 | 11,501 | 3,585,404 | 1,677,303 |
| Clay | 261,324 | 12,046 | 350,706 | 611,671 |
| Hamilton | 162,060 | 224 | 0 | 237 |
| Bosque | 135,116 | 59 | 0 | 0 |
| Kaufman | 0 | 0 | 3,002 | 61,963 |

**Table 1-3. Relationship Between the D-FW Metropolitan Area and Counties Producing Oil/Gas in the Barnett Shale Area**

| D-FW 9-County Metropolitan Area | D-FW Metro. Counties Producing Barnett Area Oil/Gas | Rural Counties Producing Barnett Area Oil/Gas |
|---|---|---|
| Tarrant | Tarrant | Wise |
| Denton | Denton | Hood |
| Parker | Parker | Jack |
| Johnson | Johnson | Palo Pinto |
| Ellis | Ellis | Stephens |
| Collin | | Hill |
| Dallas | | Eastland |
| Rockwall | | Somervell |
| Kaufman | | Comanche |
| | | Cooke |
| | | Montague |
| | | Clay |
| | | Hamilton |
| | | Bosque |

**Figure 2. Texas RRC Map of Well and Well Permit Locations in the Barnett Shale Area (red = gas wells, green = oil wells, blue = permits. RRC district 5, 7B, & 9 boundaries shown in black.)**



## 2.2 Air Pollutants and Air Quality Regulatory Efforts

Oil and gas activities in the Barnett Shale area have the potential to emit a variety of air pollutants, including greenhouse gases, ozone and fine particle smog-forming compounds, and air toxic chemicals. The state of Texas has the highest greenhouse gas (GHG) emissions in the U.S., and future federal efforts to reduce national GHG emissions are likely to require emissions reductions from sources in the state. The three anthropogenic greenhouse gases of greatest concern, carbon dioxide, methane, and nitrous oxide, are emitted from oil and gas sources in the Barnett Shale area.

At present, air quality monitors in the Dallas-Fort Worth area show the area to be in compliance with the 1997 fine particulate matter ($PM_{2.5}$) air quality standard, which is 15 micrograms per cubic meter ($\mu g/m^3$) on an annual average basis. In 2006, the Clean Air Scientific Advisory Committee for EPA recommended tightening the standard to as low as 13 $\mu g/m^3$ to protect public health, but the EPA administrator kept the standard at the 1997 level. Fine particle air quality monitors in the Dallas-Fort Worth area have been above the 13 $\mu g/m^3$ level several times during the 2000-2007 time period, and tightening of the fine particle standard by future EPA administrators will focus regulatory attention at sources that emit fine particles or fine particle-forming compounds like $NO_x$ and VOC gases.

## 2.3 Primary Emission Sources Involved in Barnett Shale Oil and Gas Production

There are a variety of activities that potentially create air emissions during oil and gas production in the Barnett Shale area. The primary emission sources in the Barnett Shale oil and gas sector include compressor engine exhausts, oil and condensate tank vents, production well fugitives, well drilling and hydraulic fracturing, well completions, natural gas processing, and transmission fugitives. Figure 3 shows a diagram of the major machinery and process units in the natural gas system.[3]

### 2.3.1 – Point Sources

*i. Compressor Engine Exhausts*

Internal combustion engines provide the power to run compressors that assist in the production of natural gas from wells, pressurize natural gas from wells to the pressure of lateral lines, and power compressors that move natural gas in large pipelines to and from processing plants and through the interstate pipeline network. The engines are often fired with raw or processed natural gas, and the combustion of the natural gas in these engines results in air emissions. Most of the engines driving compressors in the Barnett Shale area are between 100 and 500 hp in size, but some large engines of 1000+ hp are also used.

*ii. Condensate and Oil Tanks*

Fluids that are brought to the surface at Barnett Shale natural gas wells are a mixture of natural gas, other gases, water, and hydrocarbon liquids. Some gas wells produce little or no condensate, while others produce large quantities. The mixture typically is sent first to a separator unit, which reduces the pressure of the fluids and separates the natural gas and other gases from any entrained water and hydrocarbon liquids. The gases are collected off the top of the separator, while the water and hydrocarbon liquids fall to the bottom and are then stored on-site in storage tanks. The hydrocarbon liquid is known as condensate.

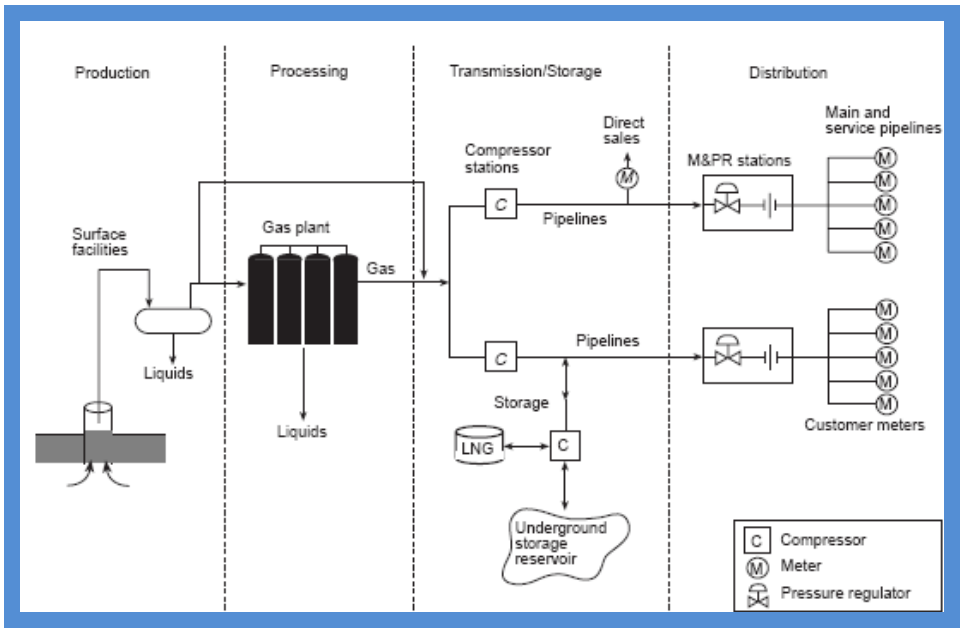



**Figure 3. Major Units in The Natural Gas Industry From Wells to Customers.** [3]

The condensate tanks at Barnett Shale wells are typically 10,000 to 20,000 gallons and hydrocarbons vapors from the condensate tanks can be emitted to the atmosphere through vents on the tanks. Condensate liquid is periodically collected by truck and transported to refineries for incorporation into liquid fuels, or to other processors. At oil wells, tanks are used to store crude oil on-site before the oil is transported to refiners. Like the condensate tanks, oil tanks can be sources of hydrocarbon vapor emissions to the atmosphere through tank vents.

2.3.2 – Fugitive and Intermittent Sources

*i. Production Fugitive Emissions*

Natural gas wells can contain a large number of individual components, including pumps, flanges, valves, gauges, pipe connectors, compressors, and other pieces. These components are generally intended to be tight, but leaks are not uncommon and some leaks can result in large emissions of hydrocarbons and methane to the atmosphere. The emissions from such leaks are called "fugitive" emissions. These fugitive emissions can be caused by routine wear, rust and corrosion, improper installation or maintenance, or overpressure of the gases or liquids in the piping. In addition to the unintended fugitive emissions, pneumatic valves which operate on pressurized natural gas leak small quantities of natural gas by design during normal operation. Natural gas wells, processing plants, and pipelines often contain large numbers of these kinds of pneumatic valves, and the accumulated emissions from all the valves in a system can be significant.

*ii. Well Drilling, Hydraulic Fracturing, and Completions*

Oil and gas drilling rigs require substantial power to from wellbores by driving drill bits to the depths of hydrocarbon deposits. In the Barnett Shale, this power is typically provided by transportable diesel engines, and operation of these engines generates exhaust from the burning of diesel fuel. After the wellbore is formed, additional power is needed to operate the pumps that move large quantities of water,

sand/glass, or chemicals into the wellbore at high pressure to hydraulically fracture the shale to increase its surface area and release natural gas.

After the wellbore is formed and the shale fractured, an initial mixture of gas, hydrocarbon liquids, water, sand, or other materials comes to the surface. The standard hardware typically used at a gas well, including the piping, separator, and tanks, are not designed to handle this initial mixture of wet and abrasive fluid that comes to the surface. Standard practice has been to vent or flare the natural gas during this "well completion" process, and direct the sand, water, and other liquids into ponds or tanks. After some time, the mixture coming to the surface will be largely free of the water and sand, and then the well will be connected to the permanent gas collecting hardware at the well site. During well completions, the venting/flaring of the gas coming to the surface results in a loss of potential revenue and also in substantial methane and VOC emissions to the atmosphere.

*iii. Natural Gas Processing*

Natural gas produced from wells is a mixture of a large number of gases and vapors. Wellhead natural gas is often delivered to processing plants where higher molecular weight hydrocarbons, water, nitrogen, and other compounds are largely removed if they are present. Processing results in a gas stream that is enriched in methane at concentrations of usually more than 80%. Not all natural gas requires processing, and gas that is already low in higher hydrocarbons, water, and other compounds can bypass processing.

Processing plants typically include one or more glycol dehydrators, process units that dry the natural gas. In addition to water, the glycol absorbent usually collects significant quantities of hydrocarbons, which can be emitted to the atmosphere when the glycol is regenerated with heat. The glycol dehydrators, pumps, and other machinery used in natural gas processing can release methane and hydrocarbons into the atmosphere, and emissions also originate from the numerous flanges, valves, and other fittings.

*iv. Natural Gas Transmission Fugitives*

Natural gas is transported from wells in mostly underground gathering lines that form networks that can eventually collect gas from hundreds or thousands of well locations. Gas is transported in pipeline networks from wells to processing plants, compressor stations, storage formations, and/or the interstate pipeline network for eventual delivery to customers. Leaks from pipeline networks, from microscopic holes, corrosion, welds and other connections, as well as from compressor intake and outlet seals, compressor rod packing, blow and purge operations, pipeline pigging, and from the large number of pneumatic devices on the pipeline network can result in large emissions of methane and hydrocarbons into the atmosphere and lost revenue for producers.

## 2.4 Objectives

Barnett Shale area oil and gas production can emit pollutants to the atmosphere which contribute to ozone and fine particulate matter smog, are known toxic chemicals, or contribute to climate change. The objectives of this study were to examine Barnett Shale oil and gas activities and : (1) estimate emissions of volatile organic compounds, nitrogen oxides, hazardous air pollutants, methane, carbon dioxide, and nitrous oxide; (2) evaluate the current state of regulatory controls and engineering techniques used to control emissions from the oil and gas sector in the Barnett Shale; (3) identify new approaches that can be taken to reduce emissions from Barnett Shale activities; and (4) estimate the emissions reductions and cost effectiveness of implementation of new emission reduction methods.

# 3.0 TECHNICAL APPROACH

## 3.1 Pollutants

Estimates were made of 2007 and 2009 emissions of smog forming, air toxic, and greenhouse gas compounds, including nitrogen oxides ($NO_x$), volatile organic compounds (VOCs), air toxics a.k.a. hazardous air pollutants (HAPs), methane ($CH_4$), nitrous oxide ($N_2O$), and carbon dioxide ($CO_2$). Volatile organic compounds are generally carbon and hydrogen-based chemicals that exist in the gas phase or can evaporate from liquids. VOCs can react in the atmosphere to form ozone and fine particulate matter. Methane and ethane are specifically excluded from the definition of VOC because they react slower than the other VOC compounds to produce ozone and fine particles, but they are ozone-causing compounds nonetheless. The HAPs analyzed in this report are a subset of the VOC compounds, and include those compounds that are known or believed to cause human health effects at low doses. An example of a HAP compound is benzene, which is an organic compound known to contribute to the development of cancer.

Emissions of the greenhouse gases $CO_2$, $CH_4$, and $N_2O$ were determined individually, and then combined as carbon dioxide equivalent tons ($CO_2e$). In the combination, $CH_4$ tons were scaled by 21 and $N_2O$ tons by 310 to account for the higher greenhouse gas potentials of these gases.[4]

Emissions in 2009 were estimated by examining recent trends in Barnett Shale hydrocarbon production, and where appropriate, extrapolating production out to 2009.

State regulatory programs are different for compressor engines inside the D-FW 9-county metropolitan area compared to outside. Engine emissions were determined separately for the two groups.

## 3.2 Hydrocarbon Production

Production rates in 2007 for oil, gas, casinghead gas, and condensate were obtained from the Texas Railroad Commission for each county in the Barnett Shale area.[5] The large amount of production from wells producing from the Barnett Shale, as well as the smaller amounts of production from conventional formations in the area were taken together. The area was analyzed in whole, as well as by counties inside and outside the D-FW 9-county metropolitan area. Production rates in 2009 were predicted by plotting production rates from 2000-2007 and fitting a 2$^{nd}$-order polynomial to the production rates via the least-squares method and extrapolating out to 2009.

## 3.3 Compressor Engine Exhausts - Emission Factors and Emission Estimates

Emissions from the natural-gas fired compressor engines in the Barnett Shale were calculated for two types of engines: the generally large engines that had previously reported emissions into the TCEQ's Point Source Emissions Inventory (PSEI) prior to 2007 (a.k.a. PSEI Engines), and the generally smaller engines that had not previously reported emissions (a.k.a. non-PSEI Engines). Both these engine types are located in the D-FW 9-county metropolitan area (a.k.a. D-FW Metro Area), as well as in the rural counties outside the metropolitan area (a.k.a. Outside D-FW Metro Area). The four categories of engines are summarized in Figure 4 and the methods used to estimate emissions from the engines are described in the following sections.

**Figure 4. Engine Categories.**

| Non-PSEI Engines in D-FW Metro Area | PSEI Engines in D-FW Metro Area | PSEI Engines Outside D-FW Metro Area | Non-PSEI Engines Outside D-FW Metro Area |
|---|---|---|---|

*i. Non-PSEI Engines in D-FW Metropolitan Area*

Large natural gas compressor engines, located primarily at compressor stations and also some at well sites, have typically reported emissions to the Texas Commission on Environmental Quality (TCEQ) in annual Point Source Emissions Inventory (PSEI) reports. However, prior to 2007, many other stationary engines in the Barnett Shale area had not reported emissions to the PSEI and their contribution to regional air quality was unknown. In late 2007, the TCEQ conducted an engine survey for counties in the D-FW metropolitan area as part as efforts to amend the state clean air plan for ozone. Engine operators reported engine counts, engine sizes, $NO_x$ emissions, and other data to TCEQ. Data summarized by TCEQ from the survey was used for this report to estimate emissions from natural gas engines in the Barnett Shale area that had previously not reported emissions into the annual PSEI.[6] Data obtained from TCEQ included total operating engine power in the metropolitan area, grouped by rich vs. lean burn engines, and also grouped by engines smaller than 50 hp, between 50 - 500 hp, and larger than 500 hp.

Regulations adopted by TCEQ and scheduled to take effect in early 2009 will limit $NO_x$ emissions in the D-FW metropolitan area for engines larger than 50 horsepower.[7] Rich burn engines will be restricted to 0.5 g/hp-hr, lean burn engines installed or moved before June 2007 will be restricted to 0.7 g/hp-hr, and lean burn engines installed or moved after June 2007 will be limited to 0.5 g/hp-hr. For this report, emissions in 2009 from the engines in the metropolitan area subject to the new rules were estimated assuming 97% compliance with the upcoming rules and a 3% noncompliance factor for engines continuing to emit at pre-2009 levels.

Emissions for 2007 were estimated using $NO_x$ emission factors provided by operators to TCEQ in the 2007 survey.[6] Emissions of VOCs were determined using TCEQ-determined emission factors, and emissions of HAPs, $CH_4$, and $CO_2$ were determined using emission factors from EPA's AP-42 document.[8,9] In AP-42, EPA provides emission factors for HAP compounds that are created by incomplete fuel combustion. For this report only those factors which were judged by EPA to be of high quality, "A" or "B" ratings, were used to estimate emissions. Emission factors for the greenhouse gas $N_2O$ were from an emissions inventory report issued by the American Petroleum Institute.[10]

Beginning in 2009, many engines subject to the new $NO_x$ limits are expected to reduce their emissions with the installation of non-selective catalytic reduction units (NSCR), a.k.a. three-way catalysts. NSCR units are essentially modified versions of the "catalytic converters" that are standard equipment on every gasoline-engine passenger vehicle in the U.S.

A likely co-benefit of NSCR installation will be the simultaneous reduction of VOC, HAP, and $CH_4$ emissions. Emissions from engines expected to install NSCR units were determined using a 75% emissions reduction factor for VOC, HAPs, and $CH_4$. Conversely, NSCR units are known to increase $N_2O$ emissions, and $N_2O$ emissions were estimated using a 3.4x factor increase over uncontrolled emission factors.[10] Table 2 summarizes the emission factors used to calculate emissions from the compressor engines identified in the 2007 survey.

**Table 2. Emission Factors for Engines Identified in the D-FW 2007 Engine Survey**

Table 2-1. Emission Factors for 2007 Emissions

| engine type | engine size | $NO_x$ (g/hp-hr)[a] | VOC (g/hp-hr)[b] | HAPs (g/hp-hr)[c] | $CH_4$ (g/hp-hr)[d] | $CO_2$ (g-hp-hr)[e] | $N_2O$ (g-hp-hr)[f] |
|---|---|---|---|---|---|---|---|
| rich | <50 | 13.6 | 0.43 | 0.088 | 0.89 | 424 | 0.0077 |
| rich | 50-500 | 13.6 | 0.43 | 0.088 | 0.89 | 424 | 0.0077 |
| rich | >500 | 0.9 | 0.43 | 0.088 | 0.89 | 424 | 0.0077 |
| lean | <500 | 6.2 | 1.6 | 0.27 | 4.8 | 424 | 0.012 |
| lean | >500 | 0.9 | 1.6 | 0.27 | 4.8 | 424 | 0.012 |

Table 2-2. Emission Factors for 2009 Emissions

| engine type | engine size | $NO_x$ (g/hp-hr)[i] | VOC (g/hp-hr)[j] | HAPs (g/hp-hr)[k] | $CH_4$ (g/hp-hr)[l] | $CO_2$ (g-hp-hr)[m] | $N_2O$ (g-hp-hr)[n] |
|---|---|---|---|---|---|---|---|
| rich | <50 | 13.6 | 0.43 | 0.088 | 0.89 | 424 | 0.0077 |
| rich | 50-500 | 0.5 | 0.11 | 0.022 | 0.22 | 424 | 0.026 |
| rich | >500 | 0.5 | 0.11 | 0.022 | 0.22 | 424 | 0.026 |
| lean[g] | <500 | 0.62 | 1.6 | 0.27 | 4.8 | 424 | 0.012 |
| lean[h] | <500 | 0.5 | 1.6 | 0.27 | 4.8 | 424 | 0.012 |
| lean[g] | >500 | 0.7 | 1.45 | 0.27 | 4.8 | 424 | 0.012 |
| lean[h] | >500 | 0.5 | 1.45 | 0.27 | 4.8 | 424 | 0.012 |

notes:

a: email from TCEQ to SMU, August 1, 2008, summary of results from 2007 engine survey (reference 6).

b: email from TCEQ to SMU, August 6, 2008 (reference 8).

c: EPA, AP-42, quality A and B emission factors; rich engine HAPs = benzene, formaldehyde, toluene; lean engine HAPs = acetaldehyde, acrolein, xylene, benzene, formaldehyde, methanol, toluene, xylene (reference 9).

d: EPA, AP-42 (reference 9).

e: EPA, AP-42 (reference 9).

f: API Compendium Report (reference 10).

g: engines installed or moved before June 2007 - TCEQ regulations establish different regulatory limits for engines installed or moved before or after June 2007 (reference 7).

h: engines installed or moved after June 2007 - TCEQ regulations establish different regulatory limits for engines installed or moved before or after June 2007 (reference 7).

i: rich (<50) factor from email from TCEQ to SMU, August 1, 2008 (reference 6); rich (50-500), rich (>500), lean (<500, post-2007), lean (>500, pre-2007), and lean (>500, post-2007) from TCEQ regulatory limits (reference 7); lean (<500, pre-2007) estimated with 90% control.

j: rich (<50) from email from TCEQ to SMU (reference 8); rich (50-500) and rich (>500) estimated with 75% NSCR control VOC co-benefit; lean EFs from email from TCEQ to SMU (reference 8). Large lean engine VOC emission factor adjusted from 1.6 to 1.45 to account for the effects of NSPS JJJJ rules on VOC emissions.

k: EPA, AP-42 (reference 9); rich (50-500) and rich (>500) estimated with 75% control co-benefit.

l: EPA, AP-42 (reference 9); rich (50-500) and rich (>500) estimated with 75% control co-benefit.

m: EPA, AP-42 (reference 9).

n: API Compendium Report (reference 10); rich (50-500) and rich (>500) estimated with 3.4x $N_2O$ emissions increase over uncontrolled rate.

Annual emissions from the engines identified in the 2007 survey were estimated using the pollutant-specific emission factors from Table 1 together with Equation 1,

$$M_{E,i} = 1.10E\text{-}06 * E_i * P_{cap} * F_{hl} \qquad (1)$$

where $M_{E,i}$ was the mass emission rate of pollutant *i* in tons per year, $E_i$ was the emission factor for pollutant *i* in grams/hp-hr, $P_{cap}$ is installed engine capacity in hp, and $F_{hl}$ is a factor to adjust for annual hours of operation and typical load conditions.

Installed engine capacity in 2007 was determined for six type/size categories using TCEQ estimates from the 2007 engine survey - two engine types (rich vs. lean) and three engine size ranges (<50, 50-500, >500 hp) were included.[6] TCEQ estimates of the average engine sizes and the numbers of engines in each size category were used to calculate the installed engine capacity for each category, as shown in Table 3. The $F_{hl}$ factor was used to account for typical hours of annual operation and average engine loads. A $F_{hl}$ value of 0.5 was used for this study, based on 8000 hours per year of average engine operation (8000/8760 = 0.91) and operating engine loads of 55% of rated capacity, giving an overall hours-load factor of 0.91x 0.55 = 0.5.[11]

**Table 3. Installed Engine Capacity in 2007 D-FW Engine Survey by Engine Type and Size**

| engine type | engine size (hp) | number of engines[q] | typical size[q] (hp) | installed capacity[r] (hp) |
|---|---|---|---|---|
| rich | <50 | 12 | 50 | 585 |
| rich | 50-500 | 724 | 140 | 101,000 |
| rich | >500 | 200 | 1400 | 280,000 |
| lean[o] | <500 | 14 | 185 | 2540 |
| lean[p] | <500 | 13 | 185 | 2400 |
| lean[o] | >500 | 103 | 1425 | 147,000 |
| lean[p] | >500 | 103 | 1425 | 147,000 |

notes:
o: engines installed or moved before June 2007 - TCEQ regulations establish different regulatory limits for engines installed or moved before or after June 2007 (reference 7).
p: engines installed or moved after June 2007 - TCEQ regulations establish different regulatory limits for engines installed or moved before or after June 2007 (reference 7).
q: rich (<50) installed capacity based on HARC October 2006 H68 report which found that small rich burn engines comprise no more than 1% of engines in East Texas; rich (50-500) and rich (>500) installed capacity from email TCEQ to SMU in August 1, 2008 (reference 6); lean burn installed capacity from email TCEQ to SMU in August 1, 2008 (reference 6) along with RRC data suggesting that 50% of engines in 2009 will be subject to the post-June 2007 NOx rule.
r: installed capacity = number of engines x typical size

*ii. PSEI Engines in D-FW Metropolitan Area*

In addition to the engines identified in the 2007 TCEQ survey of the D-FW 9-county metropolitan area, many other stationary engines are also in use in the area. These include engines that had already been reporting annual emissions to TCEQ in the PSEI, which are principally large engines at compressor stations.[12]

Emissions of $NO_x$ from large engines in the D-FW metropolitan area that were reporting to the TCEQ PSEI were obtained from the 2006 Annual PSEI, the most recent calendar year available.[12] Emissions for 2007 and 2009 were estimated by extrapolating 2006 emissions upward to account for increases in gas production and compression needs from 2006-2009. For $NO_x$ emissions in 2006 and 2007, an average emission factor of 0.9 g/hp-hr was obtained from TCEQ.[8] Emissions in 2009 were adjusted by accounting for the 0.5 g/hp-hr TCEQ regulatory limit scheduled to take effect in early 2009 for the D-FW metropolitan area.[7]

Unlike $NO_x$ emission, emissions of VOC were not taken directly from the PSEI. Estimates of future VOC emissions required accounting for the effects that the new TCEQ engine $NO_x$ limits will have on future VOC emissions. A compressor engine capacity production factor of 205 hp/(MMcf/day) was obtained from TCEQ that gives a ratio of installed horsepower capacity to the natural gas production. The 205 hp/(MMcf/day) factor was based on previous TCEQ studies of gas production and installed large engine capacity. The factor was used with 2006 gas production values to estimate installed PSEI engine capacities for each county in the Barnett Shale area.[8] Engine capacities were divided between rich burn engines smaller and larger than 500 hp, and lean burn engines. To estimate 2009 emissions, rich burn engines smaller than 500 hp are expected to have NSCR units by 2009 and get 75% VOC, HAP, and $CH_4$ control. Table 4 summarizes the VOC, HAP, and greenhouse gas emission factors used for the PSEI engines in the D-FW metropolitan area. Table 5 summarizes the estimates of installed engine capacity for each engine category.

**Table 4. VOC, HAP, GHG Emission Factors for PSEI Engines in D-FW Metropolitan Area**

Table 4-1. Emission Factors for 2007 Emissions

| engine type | engine size | VOC EFs (g/hp-hr)[s] | HAPs EF (g/hp-hr)[t] | $CH_4$ EF (g/hp-hr)[u] | $CO_2$ EF (g/hp-hr)[v] | $N_2O$ (g/hp-hr)[w] |
|---|---|---|---|---|---|---|
| rich | <500 | 0.43 | 0.088 | 0.89 | 424 | 0.0077 |
| rich | >500 | 0.11 | 0.022 | 0.22 | 424 | 0.026 |
| lean | all | 1.6 | 0.27 | 4.8 | 424 | 0.012 |

Table 4-2. Emission Factors for 2009 Emissions

| engine type | engine size | VOC EFs (g/hp-hr)[s] | HAPs EF (g/hp-hr)[t] | $CH_4$ EF (g/hp-hr)[u] | $CO_2$ EF (g/hp-hr)[v] | $N_2O$ (g/hp-hr)[w] |
|---|---|---|---|---|---|---|
| rich | <500 | 0.11 | 0.022 | 0.22 | 424 | 0.026 |
| rich | >500 | 0.11 | 0.022 | 0.22 | 424 | 0.026 |
| lean | all | 1.47 | 0.27 | 4.8 | 424 | 0.012 |

notes:

s: email from TCEQ to SMU, August 6, 2008; 75% reductions applied to 2007 rich (>500), 2009 rich (>500) and 2009 rich (<500) engines (reference 8). Large lean engine VOC emission factor adjusted from 1.6 to 1.47 to account for the effects of NSPS JJJJ rules on VOC emissions.

t: EPA, AP-42 (reference 9); 75% reductions applied to 2007 rich (>500), 2009 rich (>500) and 2009 rich (<500) engines (reference 9).

u: EPA, AP-42 (reference 9) ; 75% reductions applied to 2007 rich (>500), 2009 rich (>500) and 2009 rich (<500) engines (reference 9).

v: EPA, AP-42 (reference 9).

w: API Compendium Report; 2007 rich (>500), and 2009 rich (>500) and 2009 rich (<500) engines estimated with 3.4x $N_2O$ emissions increase over uncontrolled rate (reference 10).

**Table 5. Installed Engine Capacity in 2007 for PSEI Engines Inside D-FW Metropolitan Area**

| engine type | engine size (hp) | installed capacity (%)[x] | installed capacity (hp)[y] |
|---|---|---|---|
| rich | <500 | 0.14 | 59,500 |
| rich | >500 | 0.52 | 221,000 |
| lean | all | 0.34 | 144,000 |

notes:
x: distribution of engine types and sizes estimated from October 2006 HARC study (reference 13).
y: estimated as the installed capacity (%) x the total installed capacity based on the TCEQ compressor engine capacity production factor of 205 hp/(MMcf/day) (references 5,8).

*iii. PSEI Engines Outside D-FW Metropolitan Area*

Emissions of $NO_x$ from large engines outside the D-FW metropolitan area reporting to the TCEQ were obtained from the 2006 PSEI.[(12)] Emissions for 2007 and 2009 were estimated by extrapolating 2006 emissions upward to account for increases in gas production from 2006-2009. Unlike engines inside the metropolitan area, the engines outside the metropolitan area are not subject to the new D-FW engine rules scheduled to take effect in 2009.

In addition to the D-FW engine rules, in 2007 the TCEQ passed the East Texas Combustion Rule that limited $NO_x$ emissions from rich-burn natural gas engines larger than 240 hp in certain east Texas counties. Lean burn engines and engines smaller than 240 hp were exempted. The initial proposed rule would have applied to some counties in the Barnett Shale production area, including Cooke, Wise, Hood, Somervell, Bosque, and Hill, but in the final version of the rule these counties were removed from applicability, with the exception of Hill, which is still covered by the rule. Since gas production from Hill County is less than 3.5% of all the Barnett Shale area gas produced outside the D-FW metropolitan area, the East Texas Combustion Rule has limited impact to emissions from Barnett Shale area activity.

Emissions of VOC, HAPs, and greenhouse gases for large engines outside the D-FW metropolitan area were not obtained from the 2006 PSEI. A process similar to the one used to estimate emissions from large engines inside the metropolitan area was used, whereby the TCEQ compressor engine capacity production factor, 205 hp/(MMcf/day), was used along with actual 2007 production rates to estimate total installed engine capacity as well as installed capacity in each county for different engine categories. Pollutant-specific emission factors were applied to the capacity estimates for each category to estimate emissions. Table 6 summarizes the emission factors used to estimate emissions from engines in the PSEI outside the D-FW metropolitan area. The engine capacities used to estimate emissions are shown in Table 7.

**Table 6. VOC, HAP, GHG Emission Factors for PSEI Engines Outside D-FW Metropolitan Area**

| engine type | engine size | VOC (g/hp-hr)[z] | HAPs (g/hp-hr)[aa] | $CH_4$ (g/hp-hr)[aa] | $CO_2$ (g-hp-hr)[bb] | $N_2O$ (g-hp-hr)[cc] |
|---|---|---|---|---|---|---|
| rich | <500 | 0.43 | 0.088 | 0.89 | 424 | 0.0077 |
| rich | >500 | 0.11 | 0.022 | 0.22 | 424 | 0.026 |
| lean | all | 1.45 | 0.27 | 4.8 | 424 | 0.012 |

notes:
z: email from TCEQ to SMU, August 6, 2008; 75% control applied to rich (>500) engines (reference 8). Large lean engine VOC emission factor adjusted from 1.6 to 1.45 to account for the effects of NSPS JJJJ rules on VOC emissions.
aa: EPA, AP-42; 75% control applied to rich (>500) engines (reference 9).

bb. EPA, AP-42 (reference 9).
cc. API Compendium Report; rich (>500) engines estimated with 3.4x $N_2O$ emissions increase over uncontrolled rate (reference 10).

**Table 7. Installed Engine Capacity in 2007 for PSEI Engines Outside D-FW Metropolitan Area**

| engine type | engine size (hp) | installed capacity (%)[dd] | installed capacity (hp)[ee] |
|---|---|---|---|
| rich | <500 | 0.14 | 17,000 |
| rich | >500 | 0.52 | 62,000 |
| lean | all | 0.34 | 41,000 |

notes:
dd: distribution of engine types and sizes estimated from October 2006 HARC study (reference 13).
ee: estimated as the installed capacity (%) x the total installed capacity based on the TCEQ compressor engine capacity production factor of 205 hp/(MMcf/day) (references 5,8).

*iv. Non-PSEI Engines Outside the D-FW Metropolitan Area*

The Point Source Emissions Inventory (PSEI) only contains emissions from a fraction of the stationary engines in the Barnett Shale area, principally the larger compressor engines with emissions above the PSEI reporting thresholds. The 2007 TCEQ engine survey of engines inside the D-FW metropolitan area demonstrated that the PSEI does not include a substantial fraction of total engine emissions. Most of the missing engines in the metropolitan area were units with emissions individually below the TCEQ reporting thresholds, but the combined emissions from large numbers of smaller engines can be substantial. The results of the 2007 survey indicated that there were approximately 680,000 hp of installed engine capacity in the D-FW metropolitan area not previously reporting to the PSEI.[(6)]

Natural gas and casinghead gas production from metropolitan counties in 2007 was approximately 1,000 Bcf . A "non-PSEI" compressor engine capacity production factor of 226 hp/(MMcf/day) was determined for the Barnett Shale area. This capacity factor accounts for all the small previously hidden engines that the 2007 survey showed come into use in oil and gas production activities in the area. This production factor was used along with 2007 gas production rates for the counties outside the D-FW metropolitan area to estimate non-PSEI engine emissions from these counties. The new production factor accounts for the fact that counties outside the metro area likely contain previously unreported engine capacity in the same proportion to the unreported engine capacity that was identified during the 2007 engine survey inside the metro area. Without a detailed engine survey in the rural counties of the same scope as the 2007 survey performed within the D-FW metropolitan counties, use of the non-PSEI production factor provides a way to estimate emissions from engines not yet in state or federal inventories. The capacity of non-PSEI reporting engines in the rural counties of the Barnett Shale was determined by this method to be 132,000 hp. Emission factors used to estimate emissions from these engines, and the breakdown of total installed engine capacity into engine type and size categories, are shown in Tables 8 and 9.

**Table 8. Emission Factors for Non-PSEI Engines Outside D-FW Metropolitan Area**

| engine type | engine size | $NO_x$ (g/hp-hr)[ff] | VOC (g/hp-hr)[gg] | HAPs (g/hp-hr)[hh] | $CH_4$ (g/hp-hr)[hh] | $CO_2$ (g-hp-hr)[ii] | $N_2O$ (g-hp-hr)[jj] |
|---|---|---|---|---|---|---|---|
| rich | <50 | 13.6 | 0.43 | 0.088 | 0.89 | 424 | 0.0077 |
| rich | 50-500 | 10.3 | 0.43 | 0.088 | 0.89 | 424 | 0.0077 |
| rich | >500 | 0.89 | 0.11 | 0.022 | 0.22 | 424 | 0.026 |
| lean | <500 | 5.2 | 1.45 | 0.27 | 4.8 | 424 | 0.012 |
| lean | >500 | 0.9 | 1.6 | 0.27 | 4.8 | 424 | 0.012 |

notes:

ff: email from TCEQ to SMU, August 1, 2008 (reference 6). Rich burn engines 50-500 hp NOx emission factor adjusted from 13.6 to 10.3 to account for the effects of NSPS JJJJ rules on NOx emissions and the effect of the TCEQ East Texas Combustion Rule on Hill County production. Rich burn engines >500 adjusted from 0.9 to 0.89 to account for the effect of the TCEQ East Texas Combustion Rule on Hill County production. Lean burn <500 hp engine post-2007 emission factor adjusted from 6.2 to 5.15 to account for the effects of NSPS JJJJ rules on NOx emissions.

gg: email from TCEQ to SMU, August 6, 2008; rich (>500) based on 75% control (reference 8). Small lean engine VOC emission factor adjusted from 1.6 to 1.45 to account for the effects of NSPS JJJJ rules on VOC emissions.

hh: EPA, AP-42; rich (>500) based on 75% control (reference 9).

ii: EPA, AP-42 (reference 9).

jj: API Compendium Report; rich (>500) estimated with 3.4x $N_2O$ emissions increase over uncontrolled rate (reference 10).

**Table 9. Installed Engine Capacity for Non-PSEI Engines Outside Metropolitan Area by Engine Type/Size**

| engine type | engine size (hp) | installed capacity (%) | installed capacity (hp) |
|---|---|---|---|
| rich | <50 | 0.01 | 110 |
| rich | 50-500 | 15 | 20,000 |
| rich | >500 | 41 | 55,000 |
| lean | <500 | 0.73 | 970 |
| lean | >500 | 43 | 57,000 |

## 3.2 Condensate and Oil Tanks - Emission Factors and Emission Estimates

Condensate and oil tanks can be significant emitters of VOC, methane, and HAPs. A report was published in 2006 by URS Corporation which presented the results of a large investigation of emissions from condensate and oil tanks in Texas.[(14)] Tanks were sampled from 33 locations across East Texas, including locations in the Barnett Shale area. Condensate tanks in the Barnett Shale were sampled in Denton and Parker Counties, and oil tanks were sampled in Montague County. The results from the URS investigation were used in this study to calculate Barnett Shale-specific emission factors for VOC, $CH_4$, HAPs, and $CO_2$, instead of using a more general Texas-wide emission factor. The URS study was conducted during daylight hours in July 2006, when temperatures in North Texas are significantly above the annual average. Therefore, the results of the URS investigation were used to calculate "Peak Summer" emissions. The HAPs identified in the URS study included n-hexane, benzene, trimethylpentane, toluene, ethylbenzene, and xylene. The emission factors used to calculate peak summer emissions from Barnett

Shale condensate and oil tanks are shown in Table 10-1. Figure 5 shows a condensate tank battery from the 2006 URS study report.

**Figure 5. Example Storage Tank Battery (left), Separators (right), and Piping.[14]**

Computer modeling data were provided during personal communications with a Barnett Shale gas producer who estimated VOC, $CH_4$, HAPs, and $CO_2$ emissions from a number of their condensate tanks.[15] The tanks were modeled with ambient temperatures of 60 F, which the producer used to represent annual hourly mean temperatures in the D-FW area. These modeling results were used in this report to predict annual average condensate tank emission factors for the Barnett Shale area. The annual average emission factors are shown in Table 10-2.

**Table 10. Condensate and Oil Tank Emission Factors for the Barnett Shale.**

Table 10-1. Peak Summer Emission Factors.[14]

| | VOC (lbs/bbl) | HAPs (lbs/bbl) | $CH_4$ (lbs/bbl) | $CO_2$ (lbs/bbl) |
|---|---|---|---|---|
| condensate | 48 | 3.7 | 5.6 | 0.87 |
| oil | 6.1 | 0.25 | 0.84 | 2.7 |

Table 10-2. Annual Average Emission Factors.[15]

| | VOC (lbs/bbl) | HAPs (lbs/bbl) | $CH_4$ (lbs/bbl) | $CO_2$ (lbs/bbl) |
|---|---|---|---|---|
| condensate | 10 | 0.20 | 1.7 | 0.23 |
| oil | 1.3 | 0.013 | 0.26 | 0.70 |

Emissions for 2007 were calculated for each county in the Barnett Shale area, using condensate and oil production rates from the RRC.[5] Emissions for 2009 were estimated with the extrapolated 2000-2007 production rates for the year 2009. Emissions were calculated with Equation 2,

$$M_{T,i} = E_i * P_c * C / 2000 \qquad (2)$$

where $M_{T,i}$ was the mass emission rate of pollutant *i* in tons per year, $E_i$ was the emission factor for pollutant *i* in lbs/bbl, $P_c$ was the production rate of condensate or oil, and C was a factor to account for the reduction in emissions due to vapor-emissions controls on some tanks. For this report, the use of vapor-emissions controls on some tanks was estimated to provide a 25% reduction in overall area-wide emissions.

## 3.3 Production Fugitives - Emission Factors and Emission Estimates

Fugitive emissions from production wells vary from well to well depending on many factors, including the tightness of casing heads and fittings, the age and condition of well components, and the numbers of flanges, valves, pneumatic devices, or other components per well. A previous study published by the Gas Research Institute and U.S. EPA investigated fugitive emissions from the natural gas industry, including emissions from production wells, processing plants, transmission pipelines, storage facilities, and distribution lines.[15] Fugitive emissions of natural gas from the entire natural gas network were estimated to be 1.4% of gross production. Production fugitives, excluding emissions from condensate tanks (which are covered in another section of this report), were estimated by the GRI/EPA study to be approximately 20% of total fugitives, or 0.28% of gross production.

Production fugitive emissions from Barnett Shale operations in 2007 were estimated as 0.28% of gross natural gas and casinghead gas production of 1098 Bcf/yr. Volume emissions were converted to mass emissions with a density of 0.0483 lb/scf. Multiple Barnett Shale gas producers provided gas composition, heat content data, and area-wide maps of gas composition. The area-wide maps of gas composition were used to estimate gas composition for each producing county. These county-level data were weighted by the fraction of total area production that originated from each county to calculate area-wide emission factors. Table 11 presents the production fugitives emission factors.

**Table 11. Production Fugitives Emission Factors for the Barnett Shale.**

| VOC (lbs/MMcf) | HAPs (lbs/MMcf) | $CH_4$ (lbs/MMcf) | $CO_2$ (lbs/MMcf) |
|---|---|---|---|
| 11 | 0.26 | 99 | 1.9 |

Emissions were calculated with Equation 3,

$$M_{F,i} = E_i * P_g / 2000 \qquad (3)$$

where $M_{F,i}$ was the mass emission rate of pollutant *i* in tons per year, $E_i$ was the emission factor for pollutant *i* in lbs/MMcf, and $P_g$ was the production rate of natural and casinghead gas. The area-wide unprocessed natural gas composition based on data from gas producers was 74% $CH_4$, 8.2% VOC, 1.4% $CO_2$, and 0.20% HAPs, on a mass % basis. HAPs in unprocessed natural gas can include low levels of n-hexane, benzene, or other compounds.

## 3.4 Well Drilling, Hydraulic Fracturing Pump Engines, and Well Completions - Emission Factors and Emission Estimates

Emissions from the diesel engines used to operate well drilling rigs and from the diesel engines that power the hydraulic fracturing pumps were estimated based on discussions with gas producers and other published data. Well drilling engine emissions were based on 25 days of engine operation for a typical well, with 1000 hp of engine capacity, a load factor of 50%, and operation for 12 hours per day. Hydraulic fracturing engine emissions were based on 4.5 days of operation for a typical well, with 1000 hp of capacity, a load factor of 50%, and operation for 12 hours per day. Some well sites in the D-FW are being drilled with electric-powered rigs, with electricity provided off the electrical grid. Engines emission estimates in this report were reduced by 25% to account for the number of wells being drilled without diesel-engine power.

In addition to emissions from drilling and fracing engines, previous studies have examined emissions of natural gas during well completions. These studies include one by the Williams gas company, which estimated that a typical well completion could vent 24,000 Mcf of natural gas.[18] A report by the EPA Natural Gas Star program estimated that 3000 Mcf could be produced from typical well completions.[19] A report by ENVIRON published in 2006 describes emission factors used in Wyoming and Colorado to estimate emissions from well completions, which were equivalent to 1000 to 5000 Mcf natural gas/well.[20] Another report published in the June 2005 issue of the Journal of Petroleum Technology estimated that well completion operations could produce 7,000 Mcf. [21] Unless companies bring special equipment to the well site to capture the natural gas and liquids that are produced during well completions, these gases will be vented to the atmosphere or flared.

Discussions with Barnett Shale gas producers that are currently employing “green completion” methods to capture natural gas and reduce emissions during well completions suggests that typical well completions in the Barnett Shale area can release approximately 5000 Mcf of natural gas/well. This value, which is very close to the median value obtained from previous studies (References 18-21), was used to estimate well completion emissions in this report.

The number of completed gas wells reporting to the RRC was plotted for the Feb. 2004 – Feb. 2008 time period.[22] A least-squares regression line was fit to the data, and the slope of the line provides the

approximate number of new completions every year. A value of 1042 completions/year was relatively steady throughout the 2004-2008 time period (linear $R^2 = 0.9915$). Emissions in 2007 and 2009 from well completions were estimated using 1000 new well completions/year for each year. Emission estimates were prepared for the entire Barnett Shale area, as well as inside and outside the D-FW metropolitan area. The data from 2004-2008 show that 71 percent of new wells are being installed in the D-FW metropolitan area, 29 percent of new wells are outside the metropolitan area, and the rate of new completions has been steady since 2004. Emissions of VOC, HAPs, $CH_4$, and $CO_2$ were estimated using the same natural gas composition used for production fugitive emissions.

Some gas producers are using green completion techniques to reduce emissions, while others destroy natural gas produced during well completions by flaring. To account for the use of green completions and control by flaring, natural gas emission estimates during well completions were reduced by 25% in this report.

## 3.5 Processing Fugitives - Emission Factors and Emission Estimates

Fugitive emissions from natural gas processing will vary from processing plant to processing plant, depending on the age of the plants, whether they are subject to federal rules such as the NSPS Subpart KKK requirements, the chemical composition of the gas being processed, the processing capacity of the plants, and other factors. A previous study published by the Gas Research Institute and U.S. EPA investigated fugitive emissions from the natural gas industry, including emissions from production wells, processing plants, transmission pipelines, storage facilities, and distribution lines.[15] Fugitive emissions of natural gas from the entire natural gas industry were estimated to be 1.4% of gross production. Processing fugitives, excluding compressor engine exhaust emissions that were previously addressed in this report, were estimated to be approximately 9.7% of total fugitives, or 0.14% of gross production.

Processing fugitive emissions from Barnett Shale operations in 2007 were estimated as 0.14% of the portion of gas production that is processed, estimated as 519 Bcf/yr. Emission factors for VOC, HAPs, $CH_4$, and $CO_2$ were estimated with an area-wide natural gas composition, excluding the gas from areas of the Barnett Shale that does not require any processing. Volume emissions were converted to mass emissions with a natural gas density of 0.0514 lb/scf. Table 12 presents the processing fugitives emission factors.

**Table 12. Processing Fugitives Emission Factors for the Barnett Shale.**

| VOC (lbs/MMcf) | HAPs (lbs/MMcf) | $CH_4$ (lbs/MMcf) | $CO_2$ (lbs/MMcf) |
|---|---|---|---|
| 14 | 0.3 | 45 | 1.0 |

Processing fugitive emissions were calculated with Equation 4,

$$M_{P,i} = E_i * P_g / 2000 \qquad (4)$$

where $M_{P,i}$ was the mass emission rate of pollutant $i$ in tons per year, $E_i$ was the emission factor for pollutant $i$ in lbs/MMcf, and $P_g$ was the production rate of natural and casinghead gas. The composition of the natural gas produced in the Barnett Shale that is processed was estimated to be 65% $CH_4$, 1.5% $CO_2$, 20% VOC, and 0.48% HAPs, on a mass % basis. Not all natural gas from the Barnett Shale area requires processing.

3.6 Transmission Fugitives - Emission Factors and Emission Estimates

Fugitive emissions from the transmission of natural gas will vary depending on the pressure of pipelines, the integrity of the piping, fittings, and valves, the chemical composition of the gas being transported, the tightness of compressor seals and rod packing, the frequency of blow down events, and other factors. A previous study published by the Gas Research Institute and U.S. EPA investigated fugitive emissions from the natural gas industry, including emissions from production wells, processing plants, transmission pipelines, storage facilities, and distribution lines.[15] Fugitive emissions of natural gas from the entire natural gas industry were estimated to be 1.4% of gross production. Transmission fugitives, excluding compressor engine exhaust emissions that were previously addressed in this report, were estimated to be approximately 35% of total fugitive emissions, or 0.49% of gross production. Transmission includes the movement of natural gas from the wells to processing plants, and the processing plants to compressor stations. It does not include flow past the primary metering and pressure regulating (M&PR) stations and final distribution lines to customers. Final distribution of gas produced in the Barnett Shale can happen anywhere in the North American natural gas distribution system, and fugitive emissions from these lines are beyond the scope of this report.

Transmission fugitive emissions from Barnett Shale operations in 2007 were estimated as 0.49% of gross natural gas and casinghead gas production of 1098 Bcf/yr. Emission factors for VOC, HAPs, $CH_4$, and $CO_2$ were developed considering that a significant portion of the gas moving through the network does not require processing, while the portion of the gas with higher molecular weight compounds will go through processing. In addition, all gas will have a dry (high methane) composition after processing as it moves to compressor stations and then on to customers. Overall area-wide transmission fugitive emissions were calculated with a gas composition of 76% $CH_4$, 5.1% VOC, 1.4% $CO_2$, and 0.12% HAPs, by mass %. Table 13 presents the transmission fugitives emission factors.

**Table 13. Transmission Fugitives Emission Factors for the Barnett Shale.**

| VOC (lbs/MMcf) | HAPs (lbs/MMcf) | $CH_4$ (lbs/MMcf) | $CO_2$ (lbs/MMcf) |
|---|---|---|---|
| 12 | 0.28 | 175 | 3.3 |

Transmission fugitive emissions were calculated with Equation 5,

$$M_{tr,i} = E_i * P_g / 2000 \qquad (5)$$

where $M_{tr,i}$ was the mass emission rate of pollutant $i$ in tons per year, $E_i$ was the emission factor for pollutant $i$ in lbs/MMcf, and $P_g$ was the production rate of natural and casinghead gas.

# 4.0 RESULTS

## 4.1 Point Sources

*i. Compressor Engine Exhausts*

Emissions from compressor engines in the Barnett Shale area are summarized in Tables 14 and 15. Results indicate that engines are significant sources of ozone and particulate matter precursors ($NO_x$ and VOC), with 2007 emissions of 66 tpd. Emissions of $NO_x$ are expected to fall 50% from 32 to 16 tpd for engines in the Dallas-Fort Worth metropolitan area because of regulations scheduled to take effect in 2009 and the installation of NSCR units on many engines. Large reductions are unlikely because of the growth in natural gas production. For engines outside the D-FW metropolitan area counties, $NO_x$ emissions will rise from 19 tpd to 30 tpd because of the projected growth in natural gas production and the fact that engines in these counties are not subject to the same regulations as those inside the metropolitan area.

Emissions of volatile organic compounds are expected to increase from 15 to 21 tpd from 2007 to 2009, because of increasing natural gas production. The 2009 engine regulations for the metropolitan area counties do have the effect of reducing VOC emissions from some engines, but growth in production compensates for the reductions and VOC emissions from engines as a whole increase.

HAP emissions, which include toxic compounds such as formaldehyde and benzene, are expected to increase from 2.7 to 3.6 tpd from 2007 to 2009.

Greenhouse gas emissions from compressor engines are shown in Table 15. Emissions in 2007 as carbon dioxide equivalent tons were approximately 8900 tpd, and emissions are estimated to increase to nearly 14,000 tpd by 2009. Carbon dioxide contributed the most to the greenhouse gas emissions, accounting for approximately 90% of the $CO_2$ equivalent tons. The methane contribution to greenhouse gases was smaller for the engine exhausts than for the other sources reviewed in this report.

**Table 14. Emissions from Compressor Engine Exhausts.**

| | 2007 Pollutant (tpd) | | | | | 2009 Pollutant (tpd) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | NOx | VOC | HAPs | CH4 | CO2e | NOx | VOC | HAPs | CH4 | CO2e |
| D-FW Metro Engines | 32 | 13 | 2.2 | 35 | 7261 | 16 | 16 | 2.9 | 49 | 11294 |
| Outside Metro Engines | 19 | 2.5 | 0.45 | 7.4 | 1649 | 30 | 3.8 | 0.70 | 12 | 2583 |
| **Engines Total** | **51** | **15** | **2.7** | **43** | **8910** | **46** | **19** | **3.6** | **61** | **13877** |

**Table 15. Greenhouse Gas Emissions Details.**

| | 2007 Pollutant (tpd) | | | | 2009 Pollutant (tpd) | | | |
|---|---|---|---|---|---|---|---|---|
| | CO2 | CH4 | N2O | CO2e | CO2 | CH4 | N2O | CO2e |
| D-FW Metro Engines | 6455 | 35 | 0.20 | 7261 | 10112 | 49 | 0.28 | 11294 |
| Outside Metro Engines | 1475 | 7.4 | 0.062 | 1649 | 2310 | 12 | 0.10 | 2583 |
| **Engines Total** | **7930** | **43** | **0.26** | **8910** | **12422** | **61** | **0.38** | **13877** |

*ii. Oil and Condensate Tanks*

Emissions from condensate and oil tanks are shown in Tables 16-1 and 16-2. Annual average emissions are shown in Table 16-1, and peak summer emissions are shown in Table 16-2.

On an annual average, emissions of VOCs from the tanks were 19 tpd in 2007, and emissions will increase to 30 tpd in 2009. Because of the effects of temperature on hydrocarbon liquid vapor pressures, peak summer emissions of VOC were 93 tpd in 2007, and summer emissions will increase to 146 tpd in 2009.

Substantial HAP emissions during the summer were determined for the tanks, with 2007 emissions of 7.2 tpd and 2009 emissions of 11 tpd. Greenhouse gas emissions from the tanks are almost entirely from $CH_4$, with a small contribution from $CO_2$. Annual average greenhouse gas emissions were 95 tpd in 2007, and will increase to 149 tpd in 2009.

**Table 16. Emissions from Condensate and Oil Tanks.**

Table 16-1. Annual Average Tank Emissions

| | 2007 Pollutant (tpd) | | | | 2009 Pollutant (tpd) | | | |
|---|---|---|---|---|---|---|---|---|
| | VOC | HAPs | CH4 | CO2e | VOC | HAPs | CH4 | CO2e |
| D-FW Metro Tanks | 8.9 | 0.18 | 2.1 | 44 | 14 | 0.28 | 3.2 | 69 |
| Outside Metro Tanks | 10 | 0.21 | 2.4 | 51 | 16 | 0.32 | 3.8 | 80 |
| **Tanks Total** | **19** | **0.39** | **4.5** | **95** | **30** | **0.60** | **7.0** | **149** |

Table 16-2. Peak Summer Tank Emissions

| | 2007 Pollutant (tpd) | | | | 2009 Pollutant (tpd) | | | |
|---|---|---|---|---|---|---|---|---|
| | VOC | HAPs | CH4 | CO2e | VOC | HAPs | CH4 | CO2e |
| D-FW Metro Tanks | 43 | 3.3 | 6.7 | 142 | 67 | 5.2 | 10 | 222 |
| Outside Metro Tanks | 50 | 3.8 | 7.8 | 166 | 79 | 6.0 | 12 | 261 |
| **Tanks Total** | **93** | **7.2** | **15** | **308** | **146** | **11** | **23** | **483** |

## 4.2 Fugitive and Intermittent Sources

*i. Production Fugitives*

Emissions from fugitive sources at Barnett Shale production sites are shown in Table 17. Production fugitives are significant sources of VOC emissions, with VOC emissions expected to grow from 2007 to 2009 from 17 to 26 tpd. Production fugitives are also very large sources of methane emissions, leading to large $CO_2$ equivalent greenhouse gas emissions. Greenhouse gas emissions were 3100 tpd in 2007 and will be 4900 tpd in 2009.

**Table 17. Emissions from Production Fugitives.**

| | 2007 Pollutant (tpd) | | | | 2009 Pollutant (tpd) | | | |
|---|---|---|---|---|---|---|---|---|
| | VOC | HAPs | CH4 | CO2e | VOC | HAPs | CH4 | CO2e |
| D-FW Metro Production Fugitives | 11 | 0.27 | 102 | 2147 | 18 | 0.43 | 160 | 3363 |
| Outside Metro Production Fugitives | 5.2 | 0.12 | 46 | 971 | 8.1 | 0.19 | 72 | 1521 |
| **Production Fugitives Total** | **17** | **0.40** | **148** | **3118** | **26** | **0.62** | **232** | **4884** |

*ii. Well Drilling, Hydraulic Fracturing, and Well Completions*

Emissions from well drilling engines, hydraulic fracturing pump engines, and well completions are shown in Table 18. These activities are significant sources of the ozone and fine particulate precursors, as well as very large sources of greenhouse gases, mostly from methane venting during well completions. Greenhouse gas emissions are estimated to be greater than 4000 $CO_2$ equivalent tons per year. Based on 2000-2007 drilling trends, approximately 71% of the well drilling, fracing, and completion emissions will be coming from counties in the D-FW metropolitan area, with the remaining 29% coming from counties outside the metropolitan area.

**Table 18. Emissions from Well Drilling, Hydraulic Fracturing, and Well Completions.**

| | 2007 Pollutant (tpd) | | | | | 2009 Pollutant (tpd) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | NOx | VOC | HAPs | CH4 | CO2e | NOx | VOC | HAPs | CH4 | CO2e |
| D-FW Metro Well Drilling and Well Completion | 3.9 | 15 | 0.35 | 130 | 2883 | 3.9 | 15 | 0.35 | 130 | 2883 |
| Outside Metro Well Drilling and Well Completions | 1.6 | 6.1 | 0.14 | 53 | 1178 | 1.6 | 6.1 | 0.14 | 53 | 1178 |
| **Well Drilling and Completions Emissions Total** | **5.5** | **21** | **0.49** | **183** | **4061** | **5.5** | **21** | **0.49** | **183** | **4061** |

*iii. Natural Gas Processing*

Processing of Barnett Shale natural gas results in significant emissions of VOC and greenhouse gases, which are summarized in Table 19. Emissions of VOC were 10 tpd in 2007 and are expected to increase to 15 tpd by 2009. Greenhouse gas emissions, largely resulting from fugitive releases of methane, were approximately 670 tpd in 2007 and will be approximately 1100 tpd in 2009.

**Table 19. Emissions from Natural Gas Processing.**

| | 2007 Pollutant (tpd) | | | | 2009 Pollutant (tpd) | | | |
|---|---|---|---|---|---|---|---|---|
| | VOC | HAPs | CH4 | CO2e | VOC | HAPs | CH4 | CO2e |
| D-FW Metro Processing Fugitives | 6.7 | 0.16 | 22 | 464 | 10 | 0.26 | 35 | 727 |
| Outside Metro Processing Fugitives | 3.0 | 0.07 | 10 | 210 | 4.7 | 0.12 | 16 | 329 |
| **Processing Fugitives Total** | **10** | **0.24** | **32** | **674** | **15** | **0.37** | **50** | **1056** |

*iv. Transmission Fugitives*

Transmission of Barnett Shale natural gas results in significant emissions of greenhouse gases and VOC. Greenhouse gas emissions from transmission fugitives are larger than from any other source category except compressor engine exhausts. Emissions of VOC in 2007 from transmission were approximately 18 tpd in 2007 and are estimated to be 28 tpd in 2009. Greenhouse gas emissions from methane fugitives result in emissions of approximately 5500 tpd in 2007 and 8600 tpd in 2009. Emissions are summarized in Table 20.

**Table 20. Emissions from Natural Gas Transmission Fugitives.**

| | 2007 Pollutant (tpd) | | | | 2009 Pollutant (tpd) | | | |
|---|---|---|---|---|---|---|---|---|
| | VOC | HAPs | CH4 | CO2e | VOC | HAPs | CH4 | CO2e |
| D-FW Metro Transmission Fugitives | 12 | 0.29 | 181 | 3799 | 19 | 0.46 | 283 | 5952 |
| Outside Metro Transmission Fugitives | 5.5 | 0.13 | 82 | 1718 | 8.6 | 0.21 | 128 | 2691 |
| **Transmission Fugitives Total** | **18** | **0.43** | **262** | **5517** | **28** | **0.67** | **411** | **8643** |

4.3 All Sources Emission Summary

Emissions from all source categories in the Barnett Shale area are summarized in Table 21-1 on an annual average basis, and are summarized in Table 12-2 on a peak summer basis. Annual average emissions for 2009 of ozone and particulate precursors ($NO_x$ and VOC) were approximately 191 tpd, and peak summer emissions of these compounds were 307 tpd. The portion of those emissions originating from the 5-counties in the D-FW metropolitan area with significant oil and gas production was 133 tpd during the summer (Tarrant, Denton, Parker, Johnson, and Ellis).

Estimates of greenhouse gas emissions from the sector as a whole were quite large, with 2009 emissions of approximately 33,000 tpd. The greenhouse gas contribution from compressor engines was dominated by carbon dioxide, while the greenhouse gas contribution from all other sources was dominated by methane. Emissions of HAPs were significant from Barnett Shale activities, with emissions in 2009 of 6.4 tpd in 2009 on an annual average, and peak summer emissions of 17 tpd.

**Table 21. Emissions Summary for All Source Categories.**

Table 21-1. Annual Average Emissions from All Sources.

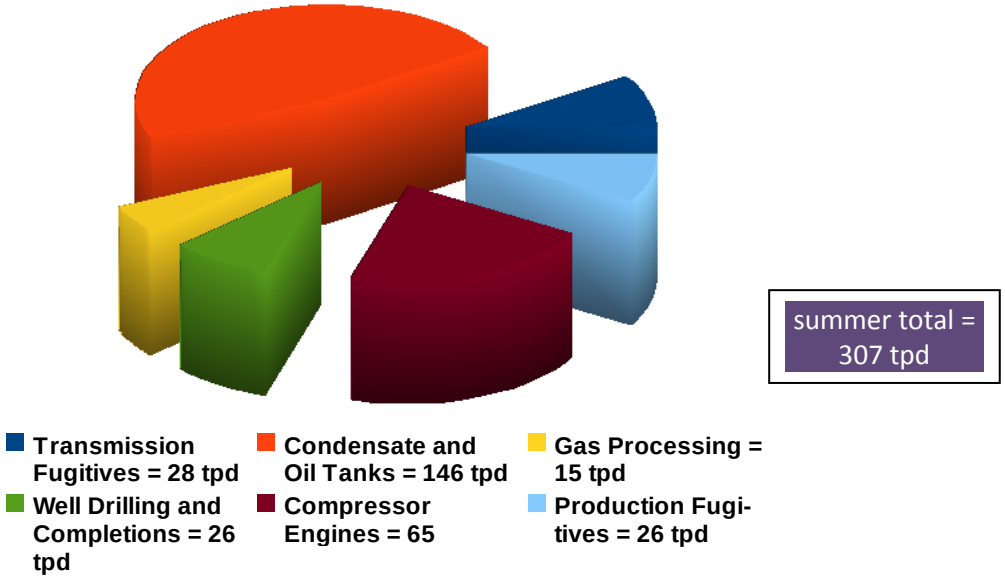
| | 2007 Pollutant (tpd) | | | | | 2009 Pollutant (tpd) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **NOx** | **VOC** | **HAPs** | **CH4** | **CO2e** | **NOx** | **VOC** | **HAPs** | **CH4** | **CO2e** |
| Compressor Engine Exhausts | 51 | 15 | 2.7 | 43 | 8910 | 46 | 19 | 3.6 | 61 | 13877 |
| Condensate and Oil Tanks | 0 | 19 | 0.39 | 4.5 | 95 | 0 | 30 | 0.60 | 7.0 | 149 |
| Production Fugitives | 0 | 17 | 0.40 | 148 | 3118 | 0 | 26 | 0.62 | 232 | 4884 |
| Well Drilling and Completions | 5.5 | 21 | 0.49 | 183 | 4061 | 5.5 | 21 | 0.49 | 183 | 4061 |
| Gas Processing | 0 | 10 | 0.24 | 32 | 674 | 0 | 15 | 0.37 | 50 | 1056 |
| Transmission Fugitives | 0 | 18 | 0.43 | 262 | 5517 | 0 | 28 | 0.67 | 411 | 8643 |
| **Total Daily Emissions (tpd)** | **56** | **100** | **4.6** | **673** | **22375** | **51** | **139** | **6.4** | **945** | **32670** |

Table 21-2. Peak Summer Emissions from All Sources.

| | 2007 Pollutant (tpd) | | | | | 2009 Pollutant (tpd) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **NOx** | **VOC** | **HAPs** | **CH4** | **CO2e** | **NOx** | **VOC** | **HAPs** | **CH4** | **CO2e** |
| Compressor Engine Exhausts | 51 | 15 | 2.7 | 43 | 8910 | 46 | 19 | 3.6 | 61 | 13877 |
| Condensate and Oil Tanks | 0 | 93 | 7.2 | 15 | 308 | 0 | 146 | 11 | 23 | 483 |
| Production Fugitives | 0 | 17 | 0.40 | 148 | 3118 | 0 | 26 | 0.62 | 232 | 4884 |
| Well Drilling and Completions | 5.5 | 21 | 0.49 | 183 | 4061 | 5.5 | 21 | 0.49 | 183 | 4061 |
| Gas Processing | 0 | 10 | 0.24 | 32 | 674 | 0 | 15 | 0.37 | 50 | 1056 |
| Transmission Fugitives | 0 | 18 | 0.43 | 262 | 5517 | 0 | 28 | 0.67 | 411 | 8643 |
| **Total Daily Emissions (tpd)** | **56** | **174** | **11** | **683** | **22588** | **51** | **255** | **17** | **961** | **33004** |

Emissions of nitrogen oxides from oil and gas production in the Barnett Shale were dominated by emissions from compressor engines, with a smaller contribution from well drilling and fracing pump engines. All source categories in the Barnett Shale contributed to VOC emissions, but the largest group of VOC sources was condensate tank vents. Figure 6 presents the combined emissions of $NO_x$ and VOC during the summer from all source categories in the Barnett Shale.

**Figure 6. Summer Emissions of Ozone & Fine Particulate Matter Precursors ($NO_x$ and VOC) from Barnett Shale Sources in 2009.**




4.4 Perspective on the Scale of Barnett Shale Air Emissions

Barnett Shale oil and gas production activities are significant sources of air emissions in the north-central Texas area. To help put the levels of Barnett Shale emissions into context, recent government emissions inventories for the area were reviewed, and emission rates of smog precursor emissions were examined.

The Dallas-Fort Worth area is home to two large airports, Dallas Love Field and Dallas-Fort Worth International Airport, plus a number of smaller airports. A recent emissions inventory has estimated 2009 $NO_x$ emissions from all area airports to be approximately 14 tpd, with VOC emissions at approximately 2.6 tpd, resulting in total ozone and particulate matter precursor emissions of approximately 16 tpd. [22-24] For comparison, emissions of VOC + $NO_x$ in summer 2009 from just the compressor engines in the Barnett Shale area will be approximately 65 tpd, and summer condensate tanks emissions will be approximately 146 tpd. In 2009, even after regulatory efforts to reduce $NO_x$ emissions from certain compressor engine types, Barnett Shale oil and gas emissions will be many times the airports' emissions.

Recent state inventories have also compiled emissions from on-road mobile sources like cars, trucks, etc., in the 9-county D-FW metropolitan area.[25] By 2009, $NO_x$ + VOC emissions from mobile sources in the 9-county area were estimated by the TCEQ to be approximately 273 tpd. The portion of on-road motor vehicle emissions from the 5-counties in the D-FW metropolitan area with significant oil and gas production was 121 tpd (Denton, Tarrant, Parker, Johnson, and Ellis). As indicated earlier, summer oil and gas emissions in the 5-counties of the D-FW metropolitan area with significant oil and gas production was estimated to be 165 tpd, indicating that the oil and gas sector likely has greater emissions than motor vehicles in these counties (165 vs. 121 tpd).

Emissions of $NO_x$ and VOC in the summer of 2009 from all oil and gas sources in the Barnett Shale 21-county area will exceed emissions from on-road mobile sources in the D-FW metropolitan area by more than 30 tpd (307 vs. 273 tpd).

Figure 7 summarizes summer Barnett Shale-related emissions, plus TCEQ emission estimates from the airports and on-road mobile sources. Figure 8 presents annual average emissions from these sources.

**Figure 7. Barnett Shale Activity, D-FW Area Airports, & Mobile Sources (Summer 2009 Emissions).**

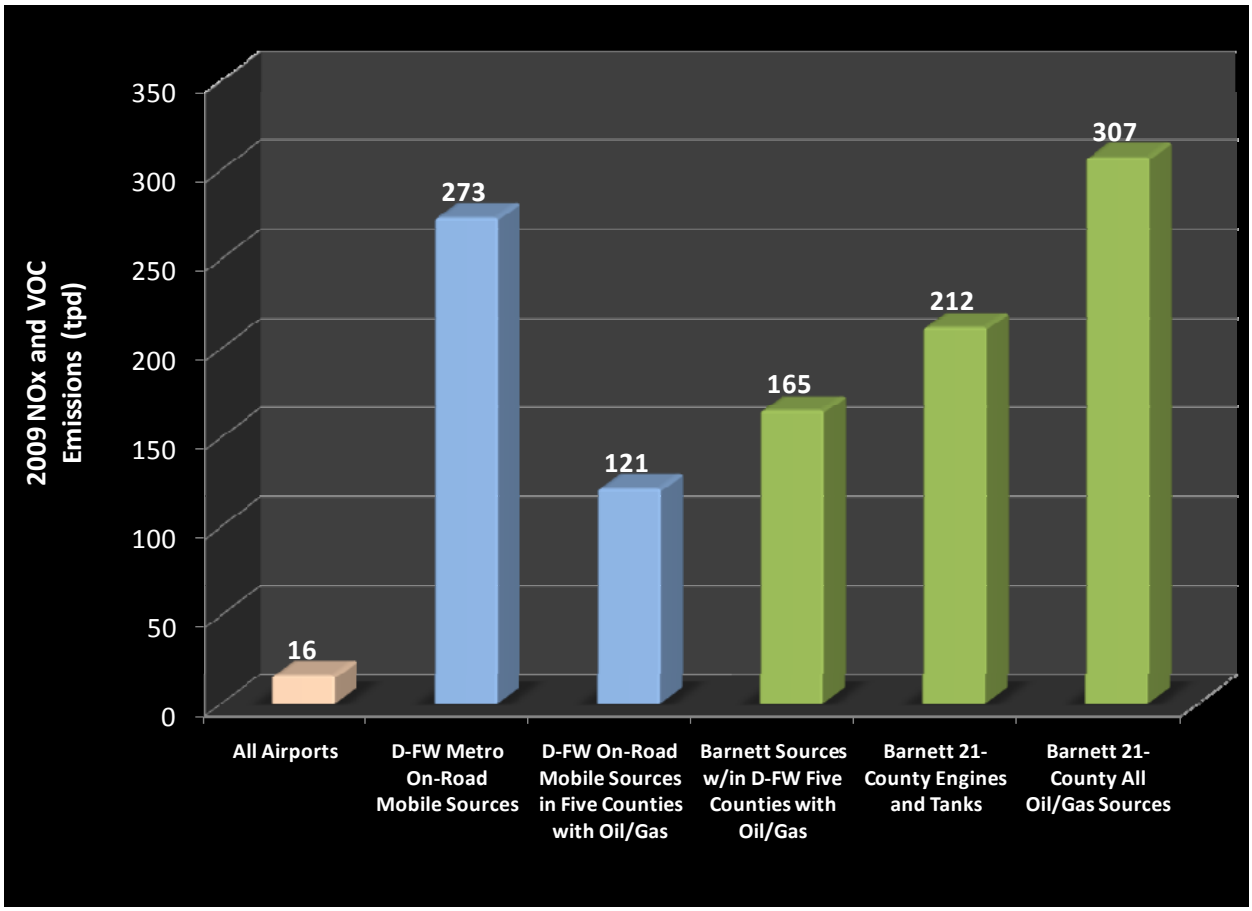
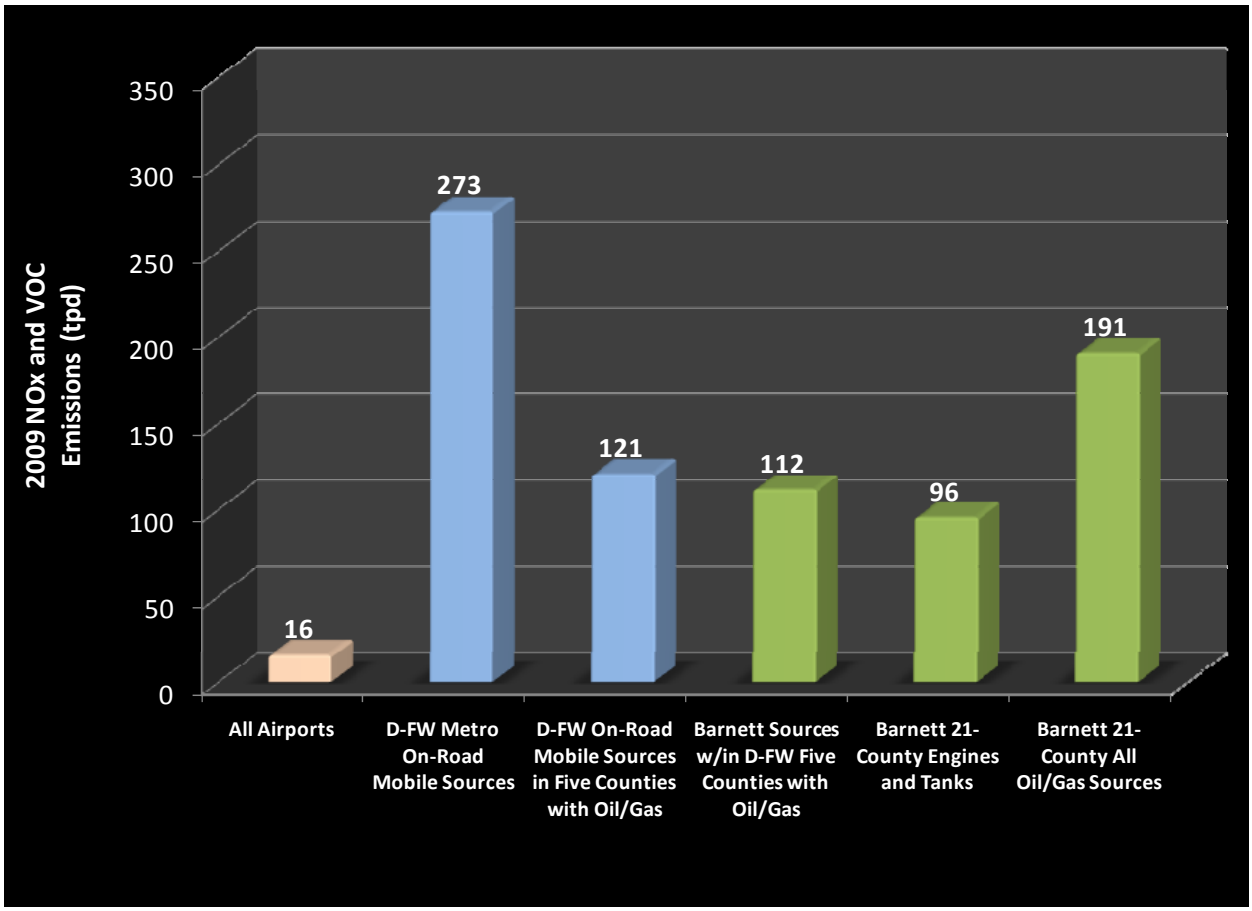


**Figure 8. Barnett Shale Activity, D-FW Area Airports, & Mobile Sources (Annual Average 2009 Emissions).**



# 5.0 EMISSIONS REDUCTION OPPORTUNITIES

The previous sections of this report have estimated the emission rates of ozone and particulate matter precursor compounds, air toxic compounds, and greenhouse gases from different oil and gas sources in the Barnett Shale area. For several of these source categories, off-the-shelf options are available which could significantly reduce emissions, resulting in important air quality benefits. Some of these emissions reductions would also result in increased production of natural gas and condensate, providing an economic payback for efforts to reduce emissions.

## 5.1 Compressor Engine Exhausts

Compressors in oil and gas service in the Barnett Shale perform vital roles, to either help get oil and gas out of the shale, to increase pressures of gas at the surface, and to provide the power for the large interstate pipeline systems that move high volumes of gas from production to processing and to customers. At present, most of the work to operate the compressors comes from natural gas-fired internal combustion engines, and these engines can be significant sources of emissions.

New TCEQ rules are scheduled to become effective in early 2009 and they will reduce $NO_x$, VOC, and other emissions from a subset of the engines in the Barnett Shale – those that are currently in the D-FW metropolitan area that had typically not reported into the Texas point source emissions inventory for major sources. These rules are a good first step in addressing emissions from these sources, which had previously gone unnoticed in state emission inventory and regulatory efforts.

However, engines outside the D-FW metropolitan area are not subject to the rule. And even within the metropolitan area, the rule will not have the effect of greatly reducing emissions in 2009 compared to 2007 levels, since growth in oil and gas production (and the new engines that are going to be required to power the growth) will begin to overtake the benefits that come from reducing emissions from the pre-2009 fleet (see Table 14).

Two available options for reducing emissions from engines in the Barnett Shale area are: (1) extending the TCEQ 2009 engine regulation to all engines in the Barnett Shale, and (2) replacing internal combustion engines with electric motors as the sources of compression power.

### *i. Extending the 2009 Engine Rule to Counties Outside the D-FW Metropolitan Area*

Regulations adopted by TCEQ for the D-FW metropolitan area and scheduled to take effect in early 2009 will limit $NO_x$ emissions from engines larger than 50 horsepower.[7] Rich burn engines will be restricted to 0.5 g/hp-hr, lean burn engines installed or moved before June 2007 will be restricted to 0.7 g/hp-hr, and lean burn engines installed or moved after June 2007 will be limited to 0.5 g/hp-hr. Applying these rules to engines outside the metropolitan area would reduce 2009 $NO_x$ emissions from a large number of engines, in particular, rich burn engines between 50 to 500 hp. Emissions of $NO_x$ in 2009 from the engines outside the metropolitan area would drop by approximately 6.5 tpd by extending the D-FW engine rule, an amount greater than mobile source emissions in all of Johnson County (4 tpd), or more than 50% of the emissions from Dallas-Fort Worth International Airport (12.6 tpd).

Extending the D-FW engine rule to counties outside the metropolitan area would likely result in many engine operators installing NSCR systems on rich burn engine exhausts. These systems would not only reduce emissions of $NO_x$, but they would also be expected to reduce emissions of VOC, the other ozone and particulate matter precursor, by approximately 75% or greater.[26a] Additional co-benefits of NSCR installations would include lower emissions of organic HAP compounds like benzene and formaldehyde, lower emissions of methane, and lower emissions of carbon monoxide. The level of HAP, methane, and

carbon monoxide control would also be expected to be 75% or greater with typical NSCR installations.[26a]

Analyses of NSCR installations and operating costs by numerous agencies have indicated that the technology is very cost effective. For example, the Illinois Environmental Protection Agency estimated in 2007 that NSCR could control $NO_x$ from 500 hp engines at approximately $330/ton.[26b] The U.S. EPA in 2006 estimated that NSCR could control $NO_x$ from 500 hp engines at approximately $92 to 105/ton.[27] A 2005 report examining emissions reductions from compressor engines in northeast Texas estimated $NO_x$ cost effectiveness for NSCR at $112-183/ton and identified VOC reductions as an important co-benefit.[28] These costs are well under the cost effectiveness values of $10,000 to $20,000 per ton often used as upper limits in $PM_{2.5}$, ozone, and regional haze (visibility) regulatory programs. The simultaneous HAPs and methane removal that would occur with NSCR use provide further justification for extending the D-FW engine rule to counties outside the metropolitan area.

*ii. Electric Motors Instead of Combustion Engines for Compressor Power*

When considering $NO_x$, VOC, HAPs, and greenhouse gas emissions from compressor engines, it is important to understand that the work to move the gas in the pipelines is performed by the compressors, which by themselves produce no direct combustion emissions. The emissions come from the exhaust of the internal combustion engines, which are fueled with a small amount of the available natural gas. These engines provide the mechanical power to run the compressors. The 2007 TCEQ engine survey and the most recent point source emissions inventory indicate that installed compressor engine capacity throughout the Barnett Shale was approximately 1,400,000 hp in 2007, and capacity is likely to increase to over 2,100,000 hp by 2009.

As an alternative to operating the compressors in the Barnett Shale with millions of hp of natural gas burning-engines, the compressors could be operated with electrically-driven motors. The electrification of the wellhead and compressor station engine fleet in the Barnett Shale area has the potential to deliver significant reductions in emissions in North Central Texas. The use of electric motors instead of internal combustion engines to drive natural gas compressors is not new to the natural gas industry, and numerous compressors driven by electric motors are operational throughout Texas. Unfortunately, current regulations have not yet required their use in the Barnett Shale.

A few of the many examples of electrically-driven natural gas compressors, positive technical assessments, and industrial experience with their use in Texas and throughout the U.S., include:

- The Interstate Natural Gas Association of America: "One advantage of electric motors is they need no air emission permit since no hydrocarbons are burned as fuel. However, a highly reliable source of electric power must be available, and near the station, for such units to be considered for an application." [29]
- The Williams natural gas company: "The gas turbine and reciprocating engines typically use natural gas from the pipeline, where the electric motor uses power from an electric transmission line. Selection of this piece of equipment is based on air quality, available power, and the type of compressor selected. Typically electric motors are used when air quality is an issue." [30]
- JARSCO Engineering Corp.: "The gas transmission industry needs to upgrade equipment for more capacity. The new high-speed electric motor technology provides means for upgrading, at a fraction of the life cycle costs of conventional gas powered equipment."[31]
- Pipeline and Gas Journal, June 2007: "Important factors in favor of electric-driven compressor stations that should be considered in the feasibility analysis include the fact that the fuel gas for

gas turbine compressor stations will be transformed into capacity increase for the electrically-driven compressor station, and will therefore add revenue to this alternative..." [32]

- Prime mover example: Installations in 2007 at Kinder Morgan stations in Colorado of +10,000 hp electric-driven compressor units. [33]
- Wellhead example: Installations in Texas of wellhead capacity (5 to 400 hp) electrically-driven compressors. [34,35]
- Mechanical Engineering Magazine, December 1996: "Gas pipeline companies historically have used gas-fired internal-combustion engines and gas turbines to drive their compressors. However, this equipment emits nitrogen oxides....According to the Electric Power Research Institute, it is more efficient to send natural gas to a combined-cycle power plant to generate electricity transmitted back to the pipeline compressor station than to burn the natural gas directly in gas-fired compressor engines."[36]
- The Dresser-Rand Corporation: "New DATUM-C electric motor-driven compressor provides quiet, emissions free solution for natural gas pipeline applications – An idea whose time had come." [37]
- Occidental Oil and Gas Corporation: "Converting Gas-Fired Wellhead IC Engines to Electric Motor Drives: Savings $23,400/yr/unit." [38]

The use of an electric motor instead of a gas-fired engine to drive gas compression eliminates combustion emissions from the wellhead or compressor station. Electric motors do require electricity from the grid, and in so far as electricity produced by power plants that emits pollutants, the use of electric motors is not completely emissions free. However, electric motor use does have important environmental benefits compared to using gas-fired engines.

Modern gas-fired internal-combustion engines have mechanical efficiencies in the 30-35% range, values that have been relatively static for decades. It is doubtful that dramatic increases in efficiency (for example, to 80 or 90%) are possible anytime in the near future. This means that carbon dioxide emissions from natural gas-fired engines at wellheads and compressor stations are not likely to drop substantially because of efficiency improvements. In addition, the scrubbing technology that is used in some large industrial applications to separate $CO_2$ from other gases also is unlikely to find rapid rollout to the thousands of comparatively-smaller exhaust stacks at natural gas wellheads and compressor stations. The two facts combined suggest that the greenhouse gas impacts from using internal combustion engines to drive compressors are likely to be a fixed function of compression demand, with little opportunity for large future improvements.

In contrast, the generators of grid electric power are under increasing pressure to lower greenhouse gas emissions. Wind energy production is increasing in Texas and other areas. Solar and nuclear power projects are receiving renewed interest from investors and regulators. As the electricity in the grid is produced by sources with lower carbon dioxide emissions, so then the use of electric motors to drive natural gas pipelines becomes more and more climate friendly.

Stated another way, carbon dioxide emissions from gas-fired engines are unlikely to undergo rapid decreases in coming years, whereas the electricity for operating electric motors is at a likely carbon-maximum right now. Electric-powered compression has a long-term potential for decreased climate impact, as non-fossil fuel alternatives for grid electricity generation expand in the future.

Costs: Estimates were made of the costs were switching from IC engines to electric motors for compression. Costs at sites in the Barnett Shale are highly time and site specific, depending on the cost of electricity and the value of natural gas, the numbers of hours of operation per year, the number and sizes of compressors operated, and other factors.

For this report, sample values were determined for capital, operating and maintenance, and operating costs of 500 hp of either IC engine capacity or electric motor capacity for a gas compressor to operate for 8000 hours per year at a 0.55 load factor. Electric power costs were based on $8/month/kW demand charge, $0.08/kWh electricity cost, and 95% motor mechanical efficiency. Natural gas fuel costs were based on $7.26/MMBtu wellhead natural gas price and a BSFC of 0.0085 MMBtu/hp-hr.

With these inputs, the wellhead value of the natural gas needed to operate a 500 hp compressor with an IC engine for 1 year is approximately $136,000. This is lower than the costs for electricity to run a comparable electric motor, which would be approximately $174,000. In addition to these energy costs, it is important to also consider operating and maintenance (O&M) and capital costs. With an IC engine O&M cost factor of $0.016/hp in 2009 dollars, O&M costs would be approximately $35,000. With an electric motor O&M cost factor of $0.0036/kWh in 2009 dollars, O&M costs would be approximately $6200, providing a savings of nearly $30,000 per year in O&M costs for electrical compression, nearly enough to compensate for the additional energy cost incurred from the additional price premium on electricity in Texas compared to natural gas.

With an IC engine capital cost factor of $750/hp in 2009 dollars, the cost of a 500 hp compressor engine would be approximately $370,000. With an electric motor cost factor of $700/kW, the cost of 500 hp of electrically-powered compression would be approximately $260,000.

The combined energy (electricity or natural gas), O&M, and capital costs for the two options are shown in Table 22, assuming a straight 5-year amortization of capital costs. The data show that there is little cost difference in this example, with a slight cost benefit of around $12,000/year for generating the compression power with an electric motor instead of an IC engine. While this estimate would vary from site to site within the Barnett Shale, there appears to be cost savings, driven mostly by reduced initial capital cost, in favor of electrical compression in the Barnett Shale. In addition to the potential cost savings of electrical compression over engine compression, the lack of an overwhelming economic driver one way or the other allows the environmental benefits of electric motors over combustion engines to be the deciding factor on how to provide compression power in the area.

**Table 22. Costs of IC Engine and Electric Motor Compression [example of 500 hp installed capacity].**

| | IC Engine ($/year) | Electric Motor ($/year) |
|---|---|---|
| energy (NG or electricity) | 136,000 | 174,000 |
| O&M | 35,000 | 6,200 |
| capital | 74,000 | 52,000 |
| **Total** | **245,000** | **232,000** |

## 5.2 Oil and Condensate Tanks

Oil and condensate tanks in the Barnett Shale are significant sources of multiple air pollutants, especially VOC, HAPs, and methane. Multiple options exist for reducing emissions from oil and condensate tanks, including options that can result in increased production and revenue for well operators.[14] This section will discuss two of these options: flares and vapor recovery units.

### *i. Vapor Recovery Units*

Vapor recovery units (VRU) can be highly effective systems for capturing and separating vapors and gases produced by oil and condensate tanks. Gases and vapors from the tanks are directed to the inlet side of a compressor, which increases the pressure of the mixture to the point that many of the moderate and higher molecular weight compounds recondense back into liquid form. The methane and other light gases are directed to the inlet (suction) side of the well site production compressors to join the main flow of natural gas being produced at the well. In this way, VRU use increases the total production of gas at the well, leading to an increase in gas available for metering and revenue production. In addition, liquids produced by the VRU are directed back into the liquid phase in the condensate tank, increasing condensate production and the income potential from this revenue stream. Vapor recovery units are estimated to have control efficiencies of greater than 98%.[14]

The gases and vapors emitted by oil and condensate tanks are significant sources of air pollutants, and the escape of these compounds into the atmosphere also reduces income from hydrocarbon production. With a wellhead value of approximately $7/MMBtu, the 7 tpd of methane that is estimated to be emitted in 2009 from condensate tanks in the Barnett Shale have a value of over $800,000 per year. Even more significantly, a price of condensate at $100/bbl makes the 30 tpd of VOC emissions in 2009 from the tanks in the Barnett Shale potentially worth over $10 million per year.

While flaring emissions from tanks in the Barnett Shale would provide substantial environmental benefits, especially in terms of VOC and methane emissions, capturing these hydrocarbons and directing them into the natural gas and condensate distribution systems would provide both an environmental benefit and a very large potential revenue stream to oil and gas producers.

### *ii. Enclosed Flares*

Enclosed flares are common pollution control and flammable gas destruction devices. Enclosed flares get their name because the flame used to ignite the gases is generated by burner tips installed within the stack well below the top. The flames from enclosed flares are usually not visible from the outside, except during upset conditions, making them less objectionable to the surrounding community compared to open (unenclosed) flares.

Using a flare to control emissions from tanks involves connecting the vents of a tank or tank battery to the bottom of the flare stack. The vapors from oil and condensate tanks are sent to the flare, and air is also added to provide oxygen for combustion. The vapors and air are ignited by natural gas pilot flames, and much of the HAP, VOC, and methane content of the tank vapors can be destroyed. The destruction efficiency for flares can vary greatly depending on residence time, temperature profile, mixing, and other factors. Properly designed and operated flares have been reported to achieve 98% destruction efficiencies.

Applying 98% destruction efficiency to the Barnett Shale oil and condensate tanks emissions estimates shown in Table 16 results in potential emission reductions of 30 tpd of VOC, 0.6 tpd of HAPs, and 7 tpd of methane. These reductions are substantial and would provide large benefits to the ozone and PM precursor, HAPs, and greenhouse gas emission inventory of the Barnett Shale area. The use of flares,

however, also has several drawbacks. One of these is that tank vapor flares need a continuous supply of pilot light natural gas, and reports have estimated pilot light gas consumption at around 20 scfh/flare.[14]

Table 23 presents a summary of the results of an economic analysis performed in 2006 by URS Corporation for using flares or vapor recovery units to control emissions from a tank battery in Texas.[14] Capital costs were estimated by URS with a 5-year straightline amortization of capital. Flow from the tank battery was 25Mscf/day and VOC emissions were approximately 211 tpy. Costs were in 2006 dollars.

**Table 23. Economics of Flares and Vapor Recovery Units.**

| Control Option | Total Installed Capital Cost ($) | Annual Installed Operating Cost ($/yr) | Operating Cost ($/yr) | Value Recovered ($/yr) | VOC Destruction Cost Effectiveness ($/ton VOC) |
|---|---|---|---|---|---|
| Enclosed Flare | 40,000 | 8000 | 900 | NA | 40 |
| VRU | 60,000 | 12000 | 11,400 | 91,300 | ($320)* |

*VRU produces positive revenue, resulting in zero cost for VOC control, after accounting for value of recovered products.

The URS analysis indicated that flares were able to cost effectively reduce VOC emissions at $40/ton, while VRU units produced no real costs and quickly generated additional revenue from the products recovered by VRU operation. There was a less-than 1 year payback on the use of a VRU system, followed by years of the pollution control device becoming steady revenue source.

## 5.3 Well Completions

Procedures have been developed to reduce emissions of natural gas during well completions. These procedures are known by a variety of terms, including "the green flowback process" and "green completions." [39,40] To reduce emissions, the gases and liquids brought to the surface during the completion process are collected, filtered, and then placed into production pipelines and tanks, instead of being dumped, vented, or flared. The gas cleanup during a "green" completion is done with special temporary equipment at the well site, and after a period of time (days) the gas and liquids being produced at the well are directed to the permanent separators, tanks, and piping and meters that are installed at the well site. Green completion methods are not complex technology and can be very cost effective in the Barnett Shale. The infrastructure is well-established and gathering line placement for the initial collection of gas is not a substantial risk since wells are successfully drilled with a very low failure rate.

Emissions during well completions depend on numerous site-specific factors, including the pressure of the fluids brought to the surface, the effectiveness of on-site gas capturing equipment, the control efficiency of any flaring that is done, the chemical composition of the gas and hydrocarbon liquids at the drill site, and the duration of drilling and completion work before the start of regular production.

Some recent reports of the effectiveness of green completions in the U.S. are available, including one by the U.S. EPA which estimated 70% capture of formerly released gases with green completions, and another report by Williams Corporation which found that 61% to 98% of gases formerly released during well completions were captured with green completions.[40-41] Barnett Shale producer Devon Energy is using green completions on its wells, and they reported $20 million in profits from natural gas and condensate recovered by green completed wells in a 3 year period.[42]

If green completion procedures can capture 61% to 98% of the gases formerly released during well completions, the process would be a more environmentally friendly alternative to flaring of the gases, since flaring destroys a valuable commodity and prevents its beneficial use. Green completions would also certainly be more beneficial than venting of the gases, since this can release very large quantities of

methane and VOCs to the atmosphere. Another factor in favor of capturing instead of flaring is that flaring can produce carbon dioxide (a greenhouse gas), carbon monoxide, polycyclic aromatic hydrocarbons, and particulate matter (soot) emissions.

5.4 Fugitive Emissions from Production Wells, Gas Processing, and Transmission

Fugitive emissions from the production wells, gas processing plants, gas compressors, and transmission lines in the Barnett Shale can be minimized with aggressive efforts at leak detection and repair. Unlike controlling emissions from comparatively smaller numbers of engines or tanks (numbering in the hundreds or low thousands per county), fugitive emissions can originate from tens of thousands of valves, flanges, pump seals, and numerous other leak points. While no single valve or flange is likely to emit as much pollution as a condensate tank or engine exhaust stack, the cumulative mass of all these fugitives can be substantial. There are readily-available measures that can reduce fugitive emissions.

*i. Enhanced Leak Detection and Repair Program*

The federal government has established New Source Performance Standards for natural gas processing plants a.k.a. NSPS Subpart KKK.[43] These standards require regularly scheduled leak detection, and if needed, repair activities for items such as pumps, compressors, pressure-relief valves, open-ended lines, vapor recovery systems, and flares. The NSPS applies to plants constructed or modified after January 20, 1984. The procedures and standards in the processing plant NSPS are generally based on the standards developed for the synthetic organic manufacturing chemicals industry.[44]

Fugitive emissions from oil and gas wells, separators, tanks, and metering stations are not covered by the processing plant NSPS. Nonetheless, the leak detection and repair protocols established in the NSPS could certainly be used to identify fugitive emissions from these other items. Leak detection at processing plants covered by the NSPS is performed using handheld organic vapor meters (OVMs), and inspections are required to be done on a specified schedule. These same procedures could be used at every point along the oil and gas system in the Barnett Shale to identify and reduce emissions of VOCs and methane. Doing so would reduce emissions, and by doing so, increase production and revenue to producers.

It is difficult to estimate the exact degree of emission reductions that are possible with fugitive emission reduction programs. The large and varied nature of fugitive emission points (valves, fittings, etc.) at production wells, processing plants, and transmission lines means that each oil and gas related facility in the Barnett Shale will have different options for reducing fugitive emissions. In general, leak detection and repair programs can help identify faulty units and greatly reduce their emissions.

*ii. Eliminating Natural Gas-Actuated Pneumatic Devices*

The State of Colorado is currently adopting and implementing VOC control strategies to reduce ambient levels of ozone in the Denver metropolitan area and to protect the numerous national parks and wilderness areas in the state. As part of this effort, the state investigated the air quality impacts of oil and gas development, including the impacts of the pneumatically-controlled valves and other devices that are found throughout gas production, processing, and transmission systems. The State of Colorado confirmed the basic conclusions arrived at earlier by EPA and GRI in 1995, that these pneumatic devices can be substantial sources of $CH_4$, VOC, and HAP emissions.[45,46] Much of the following information on these devices and the strategies to control emissions is based on a review of the recent work in Colorado.

Valves and similar devices are used throughout the oil and gas production, processing, and transmission systems to regulate temperature, pressure, flow, and other process parameters. These devices can be operated mechanically, pneumatically, or electrically. Many of the devices used in the natural gas sector

are pneumatically operated. Instrument air (i.e. compressed regular air) is used to power pneumatic devices at many gas processing facilities, but most of the pneumatic devices at production wells and along transmission systems are powered by natural gas.[46] Other uses of pneumatic devices are for shutoff valves, for small pumps, and with compressor engine starters.

As part of normal operation, most pneumatic devices release or “bleed”gas to the atmosphere. The release can be either continuously or intermittently, depending on the kind of device. In 2003 U.S. EPA estimated that emissions from the pneumatic devices found throughout the production, processing, and transmission systems were collectively one of the largest sources of methane emissions in the natural gas industry. Some U.S. natural gas producers have reduced natural gas emissions significantly by replacing or retrofitting "high-bleed" pneumatic devices. High-bleed pneumatic devices emit at least 6 standard cubic feet gas per hour.[46] Actual field experience is demonstrating that up to 80 percent of all high-bleed devices in natural gas systems can be replaced or retrofitted with low-bleed equipment.

The replacement of high-bleed pneumatic devices with low-bleed or no-bleed devices can reduce natural gas emissions to atmosphere by approximately 88 or 98 percent, respectively.[21, 47] Anadarko Petroleum Corporation estimated that VOC emissions from their pneumatic devices will be reduced by 464 tpy once 548 of their pneumatic controllers are retrofitted in Colorado.[46]

It may not be possible, however, to replace all high-bleed devices with low or no bleed alternatives. In the state of Colorado, it was estimates that perhaps up to 20 percent of high-bleed devices could not be retrofitted or replaced with low-bleed devices. Some of these included very large devices requiring fast and/or precise responses to process changes which could not yet be achieved with low-bleed devices.

But even for these devices that appear to require high-bleed operation, alternatives are available. Natural gas emissions from both high bleed and low bleed devices can be reduced by routing pneumatic discharge ports into a fuel gas supply line or into a closed loop controlled system. Another alternative is replacing the natural gas as the pneumatic pressure fluid with pressurized air. Instrument pressurized air systems are sometimes installed at facilities that have a high concentration of pneumatic devices, full-time operator presence, and are on a power grid. In an instrument pressurized air system, atmospheric air is compressed, stored in a volume tank, filtered, and dried. The advantage of a pressurized air system for operating pneumatic devices is that operation is the same whether they air or natural gas is used. Existing pneumatic gas supply piping, control instruments, and valve actuators can be reused when converting from natural gas to compressed air.

The U.S. EPA runs a voluntary program, EPA Natural Gas STAR, for companies adopting strategies to reduce their methane emissions. Experience from companies participating in the program indicates that strategies to reduce emissions from pneumatic devices are highly cost effective, and many even pay for themselves in a matter of months.[46] EPA reports that one company replaced 70 high-bleed pneumatic devices with low-bleed devices and retrofitted 330 high-bleed devices, which resulted in an emission reduction of 1,405 thousand cubic meters per year. At $105/m^3$, this resulted in a savings of $148,800 per year. The cost, including materials and labor for the retrofit and replacement, was $118,500, and therefore, the payback period was less than one year. Early replacement (replacing prior to projected end-of-service-life) of a high-bleed valve with a low-bleed valve is estimated to cost $1,350. Based on $3/m^3$ gas, the payback was estimated to take 21 months. For new installations or end of service life replacement, the incremental cost difference of high-bleed devices versus low-bleed devices was $150 to $250. Based on $3 per Mcf gas, the payback was estimated to take 5 to 12 months.[46]

Overall, cost-effective strategies are available for reducing emissions and enhance gas collection from pneumatic devices in Barnett Shale area operations. These strategies include:

- Installing low- or no-bleed pneumatic devices at all new facilities and along all new transmission lines;
- Retrofitting or replacing existing high-bleed pneumatic devices with low- or no-bleed pneumatic devices;
- Ensuring that all natural gas actuated devices discharge into sales lines or closed loops, instead of venting to the atmosphere;
- Using pressurized instrument air as the pneumatic fluid instead of natural gas.

## 6.0 CONCLUSIONS

Oil and gas production in the Barnett Shale region of Texas has increased rapidly over the last 10 years. The great financial benefits and natural resource production that comes from the Barnett Shale brings with it a responsibility to minimize local, regional, and global air quality impacts. This report examined emissions of smog forming compounds, air toxic compounds, and greenhouse gases from oil and gas activity in the Barnett Shale area, and identified methods for reducing emissions.

Emissions of ozone and fine particle smog forming compounds (NOx and VOC) will be approximately 191 tons per day on an annual average basis in 2009. During the summer, VOC emissions will increase, raising the NOx + VOC total to 307 tpd, greater than the combined emissions from the major airports and on-road motor vehicles in the D-FW metropolitan area.

Emissions in 2009 of air toxic compounds from Barnett Shale activities will be approximately 6 tpd on an annual average, with peak summer emissions of 17 tpd.

Emissions of greenhouse gases like carbon dioxide and methane will be approximately 33,000 $CO_2$ equivalent tons per day. This is roughly comparable to the greenhouse gas emissions expected from two 750 MW coal-fired power plants.

Cost effective emission control methods are available with the potential to significantly reduce emissions from many of the sources in the Barnett Shale area, including

- the use of "green completions" to capture methane and VOC compounds during well completions,
- phasing in of electric motors as an alternative to internal-combustion engines to drive gas compressors,
- the control of VOC emissions from condensate tanks with vapor recovery units, and
- replacement of high-bleed pneumatic valves and fittings on the pipeline networks with no-bleed alternatives.

Large reductions in greenhouse gas emissions could be achieved through the use of green completion methods on all well completions, with the potential to eliminate almost 200 tpd of methane emissions while increasing revenue for producers by recovering saleable gas. In addition, the replacement of internal combustion engines with electric motors for compression power could reduce smog-forming emissions in the D-FW metropolitan area by 65 tpd. Significant emission reductions could also be achieved with the use of vapor recovery units on oil and condensate tanks, which could eliminate large amounts of VOC emissions. Vapor recovery units on condensate tanks would pay for themselves in a matter of months by generating additional revenue to producers from the gas and condensate that would be captured instead of released to the atmosphere. Fugitive emissions of methane, VOC, and HAPs could be reduced with a program to replace natural gas actuated pneumatic valves with units actuated with compressed air. For those devices in locations where compressed air is impractical to implement, connection of the bleed vents of the devices to sales lines also could greatly reduce emissions.

There are significant opportunities available to improve local and regional air quality and reduce greenhouse gas emissions by applying readily available methods to oil and gas production activities in the Barnett Shale.

## 7.0 REFERENCES


1. Railroad Commission of Texas, "Barnett Shale Information – Updated July 30, 2008."
on-line document: http://www.rrc.state.tx.us/barnettshale/index.html

2. Railroad Commission of Texas, "Newark, East (Barnett Shale) Field – Map – April 17, 2008." RRC Geographic Information Systems, Austin, Texas.
on-line database: http://www.rrc.state.tx.us/divisions/og/maps/index.html

3. U.S. Environmental Protection Agency and the Gas Research Institute, "Methane Emissions from the Natural Gas Industry." EPA/600/SR-96/080, GRI-94/0257. June 1996.
on-line document: http://www.epa.gov/gasstar/documents/emissions_report/1_executiveummary.pdf and http://www.p2pays.org/ref%5C07/06348.pdf

4. U.S. Environmental Protection Agency, "Greenhouse Gases and Global Warming Potential Values – Excerpt from the Inventory of U.S. Greenhouse Emissions and Sinks: 1990-2000."
April 2002.
on-line document: http://www.epa.gov/climatechange/emissions/downloads/ghg_gwp.pdf

5. Railroad Commission of Texas, "Oil and Gas Production Data Query."
on-line database: http://webapps.rrc.state.tx.us/PDQ/home.do

6. Personal communication: TCEQ to SMU, summary of results of 2007 Barnett Shale/D-FW compressor engine survey, August 1, 2008.

7. Texas Commission on Environmental Quality, "Revisions to the State Implementation Plan (SIP) for the Control of Ozone Air Pollution – Dallas-Fort Worth Eight-Hour Ozone Nonattainment Area Attainment Demonstration." Project No. 2006-013-SIP-NR. May 23, 2007. on-line document:
http://www.tceq.state.tx.us/assets/public/implementation/air/sip/D-FW/D-FW_ad_sip_2007/2006013SIPNR_ado_Intro_052407.pdf

8. Personal communication: TCEQ to SMU, compressor engine emission factors, August 6, 2008.

9. U.S. Environmental Protection Agency, "Natural Gas-fired Reciprocating Engines." AP-42, Fifth Edition, Volume I. July 2000.
on-line document: http://www.epa.gov/ttn/chief/ap42/ch03/index.html

10. American Petroleum Institute, "Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry." February 2004.
on-line document: http://www.api.org/ehs/climate/new/upload/2004_COMPENDIUM.pdf

11. ENVIRON International Corporation, "A Pilot Project to Assess the Effectiveness of an Emission Control System for Gas Compressor Engines in Northeast Texas – Final Report." November 4, 2005.
on-line document:
http://www.epa.gov/oar/ozonepollution/SIPToolkit/documents/NETAC_Compressor_Retrofit_Final_Report_110405.pdf

12. Texas Commission on Environmental Quality, "Point Source Emissions Inventory – 2006 Report."
on-line document: http://www.tceq.state.tx.us/implementation/air/industei/psei/psei.html

13. Eastern Research Group, "Natural Gas Compressor Engine Survey for Gas Production and Processing Facilities – H68 Final Report." a report prepared for the Houston Advanced Research Center. October 5, 2006.
on-line document: http://files.harc.edu/Projects/AirQuality/Projects/H068/H068FinalReport.pdf

14. Hendler A., Nunn J., Lundeen J., McKaskle R. "VOC Emissions from Oil and Condensate Storage Tanks – Final Report," a report prepared for the Houston Advanced Research Center. October 31, 2006.
on-line document: http://files.harc.edu/Projects/AirQuality/Projects/H051C/H051CFinalReport.pdf

15. Personal communication with Barnett Shale gas producer – condensate tank emissions modeling results, 2008.

16. George D.L. "Preparation of Natural Gas Blends Used as Calibration Standards: Sources of Uncertainty and Best Preparation Practices – Final Report." Southwest Research Institute, San Antonio, Texas. April 2003.
on-line document:
http://www.mms.gov/tarprojects/278/calGasAccuracy_final.pdf

17. ENVIRON International Corporation, "Ozone Precursor Emission Inventory for San Juan and Rio Arriba Counties, New Mexico – Final Report." a report prepared for New Mexico Environment Department. August 31, 2006.
on-line document:
http://www.nmenv.state.nm.us/aqb/projects/San_Juan_Ozone/NM_Area_Emissions_report.pdf

18. The Williams Companies, "Reducing Methane Emissions During Completion Operations." Williams Production RMT – Piceance Basin Operations. 2007 Natural Gas Star - Production Technology Transfer Workshop. September 11, 2007.
on-line document: http://www.epa.gov/gasstar/documents/workshops/glenwood-2007/04_recs.pdf

19. U.S. Environmental Protection Agency, "Green Completions." PRO Fact Sheet No. 703. EPA Natural Gas Star, Partner Reported Opportunities for Reducing Methane Emissions. September 2004.
on-line document:
http://www.epa.gov/gasstar/documents/greencompletions.pdf

20. ENVIRON International Corporation, ""An Emission Inventory of Nonpoint Oil and Gas Emissions Sources in the Western Region," 15th Annual Emissions Inventory Conference, New Orleans, LA. May 2006.
on-line document: http://www.epa.gov/ttn/chief/conference/ei15/session12/russell.pdf

21. Fernandez R. et al, "Cost-Effective Methane Emissions Reductions for Small and Midsize Natural Gas Producers." Journal of Petroleum Technology, June 2005.
on-line document: http://www.icfi.com/Markets/Environment/doc_files/methane-emissions.pdf

22. Texas Commission on Environmental Quality, "Dallas-Fort Worth Eight Hour Ozone State Implementation Plan, Supplemental Information." letter from Susana M. Hildebrand to Thomas Diggs, April 23, 2008.
on-line document:
http://www.tceq.state.tx.us/assets/public/implementation/air/sip/D-FW/TCEQ_Response.pdf

23. Love Field Airport, "2005 Emission Inventory." November 3, 2006.

24. Dallas/Fort Worth International Airport, "D-FW Emissions Forecast." March 21, 2008.

25. ENVIRON International Corporation, "Ozone Impacts in D-FW from Revised Emission Controls in the 2009 Future Year – Final Report." August 31, 2007.
on-line report:
http://www.tceq.state.tx.us/assets/public/implementation/air/am/docs/D-FW/p1/D-FW_Control_Modeling_Final_Report-20070831.pdf

26a. Colorado Department of Public Health and Environment, Air Pollution Control District, "Control of Compressor Engine Emissions, Related Costs and Considerations." October 31, 2003.
on-line report:
http://apcd.state.co.us/documents/eac/reportoct31.doc

26b. Illinois Environmental Protection Agency, "Technical Support Document for Controlling NOx Emissions from Stationary Reciprocating Internal Combustion Engines and Turbines." Report AQPSTR 07-01. March 19, 2007.
on-line report:
http://www.epa.state.il.us/air/rules/rice/tsd-rice.pdf

27. U.S. Environmental Protection Agency, "Draft Estimates of Cost Effectiveness of Non-Selective Catalytic Reduction for Rich-burn IC Engines (from March 21, 2006)." information from Jaime Pagan of OAQPS.

28. ENVIRON International Corporation, "Demonstration of NOx Emission Controls for Gas Compressor Engines – A Study for Northeast Texas." December 6, 2005.
on-line document:
http://www.epa.gov/air/ozonepollution/SIPToolkit/documents/12-20-05_rich-burn_engine_control_briefing.pdf

29. Interstate Natural Gas Association of America, "Interstate Gas Pipeline Systems - Prime Movers."
on-line document:
http://engr.smu.edu/~aja/2007-ozone-report/INGAA.pdf

30. Williams Companies, "Compressor Facility - Project Overview and Facility Design."
on-line document:
http://engr.smu.edu/~aja/2007-ozone-report/Williams-Gas.pdf

31. Oliver J.A., Samotyj M.J. "Electrification of Natural Gas Pipelines – A Great Opportunity for Two Capital Intensive Industries." IEEE Transactions on Energy Conversion, vol. 14, pp. 1502-1506, December 1999.
on-line document:
http://ieeexplore.ieee.org/search/wrapper.jsp?arnumber=815097

32. Mokhatab S. "Compressor Station Design Criteria." Pipeline and Gas Journal, June 2007.
on-line document:
http://findarticles.com/p/articles/mi_m3251/is_/ai_n25008106?tag=artBody;col1

33. Ranger Plant Construction Company, Inc., Abilene, Texas.
on-line document:
http://www.rpcabilene.com/history-1.html

34. Wellhead Compressors, Inc., Midland, Texas.
on-line document:
http://wellheadcompressors.com/products/index.html

35. EnerSource Compression Systems, Inc., Odessa, Texas.
on-line document:
http://www.gascompressor.com/gasgather.htm

36. Valenti M. "Gas Pipelines Go Electric." Mechanical Engineering, December 1996.
on-line document:
http://www.memagazine.org/backissues/december96/features/gaspipe/gaspipe.html

37. Dresser-Rand Corporation, "New Datum-C Electric Motor-Driven Compressor Provides Quiet, Emission-Free Solution for Natural Gas Pipeline Applications." Dresser-Rand Insights, vol. 8, no. 1, 2005.
on-line document:
http://www.dresser-rand.com/insight/v8n01/art_2.asp

38. Occidental Oil and Gas Corporation, "Technical Barriers to Emissions Reductions: Gas STAR Case Studies." September 26, 2006.
on-line document:
http://www.ipieca.org/activities/climate_change/downloads/workshops/26sept_06/Session_3/Ravishanker.pdf

39. Integrated Production Services, "Green Flowback Process." presentation at Texas A&M University – Corpus Christi, Improved Profits Through Best Managed Practices.
on-line document:
http://www.epa.gov/gasstar/documents/workshops/houston-2005/green_flowback.pdf

40. U.S. Environmental Protection Agency, "Green Completions - Methane Emissions Reductions." PRO Fact Sheet No. 703. EPA Natural Gas Star, Partner Reported Opportunities for Reducing Methane Emissions. September 2004.
on-line document:
http://www.epa.gov/gasstar/documents/greencompletions.pdf

41. The Williams Companies, "Reducing Methane Emissions During Completion Operations – Economics Volume Recovered." Williams Production RMT – Piceance Basin Operations. 2007 Natural Gas Star - Production Technology Transfer Workshop. September 11, 2007.
on-line document:
http://www.epa.gov/gasstar/documents/workshops/glenwood-2007/04_recs.pdf

42. Devon Energy, "EPA Natural Gas Star Program – Economics of FWB RECs."
on-line document:
http://www.spe.org/spe-site/spe/spe/meetings/EPESC/2007/GreenhouseGas_BrianWoodward.pdf

43. U.S. Environmental Protection Agency, "Standards of Performance for Equipment Leaks of VOC from Onshore Natural Gas Processing Plants." 40 CFR Part 60, Subpart KKK.

44. U.S. Environmental Protection Agency, "Standards of Performance for Equipment Leaks of VOC in the Synthetic Organic Chemicals Manufacturing Industry for Which Construction, Reconstruction, or Modification Commenced After January 5, 1981, and on or Before November 7, 2006." 40 CFR Part 60, Subpart VV.

45. ENVIRON International Corporation, "Development of Baseline 2006 Emissions from Oil and Gas Activity in the Denver-Julesburg Basin." a report prepared for the Colorado Department of Public Health and Environment. April 30, 2008.

46. Colorado Air Pollution Control Division, "High Bleed Pneumatic Devices." presented at the April 10, 2008 RAQC Meeting.
on-line document:
http://www.cdphe.state.co.us/ap/ozone/RegDevelop/IssuePapers/April4-08/APCDOZISSUEPAPERpneumaticdevicesRev1.pdf

47. ENVIRON International Corporation, "WRAP Area Source Emissions Inventory Projections and Control Strategy Evaluation Phase II - Final Report," September 2007.
on-line document:
http://www.wrapair.org/forums/ssjf/documents/eictts/OilGas/2007-10_Phase_II_O&G_Final)Report(v10-07%20rev.s).pdf

*Author's Notes:*

*A draft version of this report was prepared in September 2008 and distributed for review and comment to oil and gas producers, state and federal regulators, authors of some of the references used in this report, and others. The author appreciates the comments received by those reviewers and the time they took to provide feedback. For the purpose of full disclosure, the author notes that he was an employee with Radian International LLC working on projects for several gas industry clients, including the Gas Research Institute and gas pipeline companies, during the time that "Methane Emissions from the Natural Gas Industry" (Reference 15) was published. The authors of Reference 15 were also employees of Radian International LLC, working as contractors for the Gas Research Institute and the Environmental Protection Agency. The author of this study notes that he did not work on or participate in the GRI/EPA project performed by the other Radian International personnel.*

*Images on the cover page from the Texas Railroad Commission and the U.S. Department of Energy.*

*Some typos and spreadsheet errors fixed on 2/8/2009.*

*Finally, the statements and recommendations in this study are those of the author, and do not represent the official positions of Southern Methodist University.*